Bertil Dahlberg

THE MASTICATORY EFFECT

A NEW TEST AND AN ANALYSIS OF MASTICATION IN MORE OR LESS DEFECTIVE SET OF TEETH

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Preface.

This work is divided into two sections. In Part I a new mastication test is discussed, which is based on older tests that have, however, been very much modified. Further, a method has been worked out of calculating the effect of mastication, which has resulted in a mastication coefficient. The aim has been to make the method possible for practical use, and also to render it sufficiently easy to use for mass investigations.

In Part II an investigation has been made of the chewing in persons of different sex and age (children, adults and old people), and in groups with sets of teeth of varying nature. In the first place, the quality of the teeth has been investigated in the above-mentioned groups, made from an average population. The number of chews and the effect of mastication have been analysed, and, finally, an investigation has been made of chewing with full dentures.

When working out the methods, the author was given working facilities in the Physiological Institution, Uppsala. I should like to offer my warm thanks to Professor Torsten Teorell for the kindness and interest he has shown me, and the advice I have had from him. This applies in particular to the working out of colorimetrical determinations of the test portions' degree of reduction.

In the statistical treatment of the material, place at the State Institute of Race Biology was put at my disposal. I would like to thank the Head of the Institute, Professor Gunnar Dahlberg, for his kindness here, and for the advice he gave me during the statistical analysis. I should further like to thank Miss Ingegerd Plyhr, Miss Martha Adler and Mr Gustaf Kujahn for their painstaking work of calculation.

The translation has been carried out by Carolyn Hannay, M. A., and to her, too, I offer my warm thanks.

Bertil Dahlberg.

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Chapter 1.

Survey of the literature.

If we leave out of account the importance of the teeth for appearance and speech, it is plain that their sole task is to divide up the food into small pieces. In odontology attention has primarily been paid to diseases connected with the teeth and the paradentium. As a matter of fact, no very great interest has been shown to the function of the teeth under physiological and pathological conditions, although the effect of mastication no doubt could be called a central problem within odontology.

It is, however, not only of theoretical but also of practical importance to get an idea of the masticatory powers in different sets of teeth. When, for example, a conscript is to be judged for military service, it stands to reason that some regard must also be paid to the state of his teeth and his powers of mastication. It has, however, not been possible to reach generally accepted norms by applying viewpoints of military hygiene to the teeth, since there has been no very exact knowledge as to how far the powers of mastication decline when the condition of the teeth gets worse. One of the few authors who has made any statement on this point is KANTOROWICZ, 1932, who says that the experiences during the World War 1914—1918 would show that 3—3 $^1/_2$ pairs of molars or bicuspids should ensure fitness for military service. No investigations seem to have been made to substantiate rules of this kind.

In practical dentistry, a closer knowledge of the masticatory effect and its relation to the number of teeth is necessary — for example, when deciding whether a patient requires prosthesis. There is no doubt that an almost complete loss of teeth definitely indicates artificial ones. There is a stage between extremely defective sets of teeth and almost complete ones where, according to Kantorowicz, it can be said that »wo man die Grenze für die Notwendigkeit des Ersatzes ziehen will bleibt in gewissem Masse der Willkür überlassen». It is, of course, a perfectly tenable view

that every defect in the set of teeth should be restored as far as possible, not only to keep the masticatory powers at as high a level as possible, but above all to prevent secondary consequences on the antagonist teeth and adjacent teeth, and also on the set as a whole. It is difficult in practical work to act consistently according to such norms, and it is therefore of particular interest, when deciding if the patient requires artificial teeth, to have a clear idea of the masticatory powers in relation to the number of teeth.

Kantorowicz maintains that the powers of mastication are palpably diminished with the loss of five or more units, so that prosthesis is needed. In this connection, one pair of molars in an antagonist position is regarded as one unit, and other pairs of teeth as half a unit. This rule is not, however, based on investigations showing that just such a loss of teeth is definitely detrimental to masticatory powers to this extent. At present it is not possible to motivate fixed indications for prosthetic replacement, since it is not known how many teeth of different types can be missing without serious detriment to the powers of mastication. In other words, it is not possible to give the patient definite reasons for the degree of toothlessness at which replacements are necessary. The result of this is that it is often the patient himself who decides when such treatment is to be undertaken, and this almost always means that the treatment is begun unnecessarily late; i. e. not until the patient himself cannot stand the situation any longer and, in many cases, only after pronounced anomalies in the set of teeth and their position have further impaired the powers of mastication.

Finally, it may be recalled in passing that a connection may exist between impaired masticatory powers and disturbances in the gastro-intestinal canal. These problems have met with lively scientific interest and a large number of investigations have been carried out to show this connection in more detail. It is fairly well agreed that, if the gastro-intestinal canal is pathologically disturbed, poor mastication has a harmful effect on the course and duration of the complaint. Actually, though, we have no exact knowledge as to the importance of the teeth in this respect. Questions of this kind can only be answered when we are able to decide both how far an incomplete set of teeth decreases the masticatory powers, and the extent to which the gastro-intestinal canal receives far too inadequately chewed food when teeth are missing.

Although the problems connected with the powers and the effect of mastication have both theoretical and practical interest, the odontological literature contains only a few works which deal with them in more detail. The present survey will deal first with the methods used for determining the effect of mastication, and then give a short account of the results obtained by them.

The methods used.

The first to deal with the problem was CHRISTIANSEN, 1922. The aim of his investigation was to determine whether complete prostheses, mounted according to the articulation method, were better able to reduce food than such as were mounted according to the occlusion method — i. e. in an ordinary hinge-articulator. Christiansen's procedure in his experiments was first to supply several suitable subjects with a double set of complete prostheses, the teeth being in articulation in the one and in occlusion in the other. When the patients had got used to both of these, they were given a certain substance to chew, which was then examined. The substance chosen as test material was cylinders of Spanish hazel-nut for the first experiments; later, however, cocoanut was used, though Christiansen says that this latter is tougher and more troublesome to chew, and gives results inferior to those obtained with hazel-nuts. He gives no reasons why he continues to use cocoanut. It is further to be noted that neither the weight nor the volume of the portions are given.

The experiments were carried out in the following way. The patient was made to chew the test material 50 times, and then spit it out into a measuring-glass with a volume of 500 c. cm. The glass was filled with water up to the 500 line and the contents poured into a strainer, after which the same amount of water was poured through five times. The apparatus consisted of four containers one above the other, each with a straining-net with meshes of $^1/_3$, $^1/_2$, 1 and 2 mm. a side. After straining, the four fractions were dried in a drying-cupboard at 100° C, and when constant weight had been reached — which was calculated to take place after an hour — each fraction was weighed. Each quantity was then reckoned in per cent of the total weight.

As Christiansen has given no data as to the reliability of the method, it is not known how far the results vary from one occasion to the next, when the experiments are repeated on the same

person. It is therefore impossible to determine how far the method yields satisfactory results. There is, however, reason to suppose that a straining in the simple apparatus and with the small amount of rinsing-water that Christiansen used would give fairly uncertain figures.

Christiansen is nevertheless the first to present and seek to solve the problem by testing out the effect of mastication on a definite material. The method he gives has been taken up by later authors. Thus, in an investigation in 1928 using on the whole the same methods, BALTERS tried to compare the effect of mastication with prostheses made with and without regard to the individual path of the condyles. The alterations made by Balters in the method were that the size of the straining-nets was increased (0.30, 0.75, 2 and 3 mm.), and that the strainers were rinsed with water from a rubber tube attached to the water-tap. This rinsing method is an improvement; a source of error is, however, to be found in there having been no arrangements made to standardize the rinsing. Balters gave neither the time for rinsing, the water pressure nor the amount of water used during straining. In this investigation, too, the test material was cocoanut. The fractions were dried in a drying cupboard at 100°, and weighed.

In 1932 JUUL investigated the masticatory powers in children with normal and abnormal occlusion. The method is the same as that used by Christiansen and Balters, cocoanut being used as test material to a weight of 6.5 g. per portion. The holes in the strainers had about the same size as in the one used by Balters. It should, however, be mentioned that the meshes of the finished nets, which are mass-produced are not all the same size, since the wires cross each other without being fixed at each intersection. Differences between the meshes can clearly be seen in figures given in the paper. Juul gives the mean size of the meshes and uses a network where they are on an average 0.4, 1, 1.5 and 2 mm.

An investigation of the masticatory powers of adults with their own teeth was carried out by ASCHER in 1938. The method differs only in a few points from that of Christiansen. Instead of cocoanut, Ascher used peeled Brazil-nut for test material. The quantity per portion, 3.5 g., was about half the amount of cocoanut Juul tried on children. Comparing cocoanut und Brazil-nut from the point of view of mastication, there is reason to suppose that the latter is more suitable as test material, since it has a

fairly homogeneous consistency; cocoanut, on the other hand, has a tendency to disintegrate during mastication along lines of cleavage implicit in its structure. When determining the coarseness of the network in the strainers, Ascher has used the rules in Deutsches Arzeneibuch for strainers used in sorting chopped herbal drugs and pulverized medicaments. He decided on meshes of 0.30, 0.75, 2 and 3 mm. a side. In the sorting, drying and weighing of the fractions, Ascher's method tallies with those of previous investigators.

The masticatory powers in adults with their own teeth have also been investigated by GELMAN, 1932. The method he used is relatively simple and differs in important points from that of Christiansen. The test material consisted of sweet almonds, with about four almonds, corresponding to approximately 5 g. of substance, to each portion. The test subjects were made to chew not a fixed number of times but for a fixed period, on an average 50 seconds; the author has not shown why this latter method should be preferred to the former one. The number of chews per time unit varies very considerably, since different people chew at different rates according to habit or temperament.

In contrast to Christiansen, Gelman dried the fractions over a water bath instead of in a drying-cupboard at 100°, before the sorting out of the particles into different sizes. He considers drying in a drying-cupboard inadvisable, as he is afraid the chewed particles might change their shape during the process. It goes without saying, that there is shrinking of the particles, since the test material contains water which drying causes more or less to evaporate. If the particles are first sorted by means of the strainers, there is nothing to prevent the drying being carried out afterwards, provided it is taken far enough to be expected to give constant weight. The objection can, however, be made to drying the chewed fractions in a drying cupboard, that there is no guarantee the process will, as regards different-sized particles, be the same from case to case. Obviously the largest particles will not, in the same time, loose as much water as the smallest ones. Gelman's method of first drying the chewed mass over a water bath and then sorting the dried particles is uncertain, as such a drying will probably be fairly uneven and subject to chance. If, on the one hand, the drying goes on too long, the particles shrink and the straining is affected. On the other hand, if the mass is only slightly dried, it affects the

results of the weighing. It is plain that Gelman did not consider these points of view, since he states he dried the mass for 10—40 minutes, and thus did not use a constant time.

The straining was done by shaking the dried mass through a single strainer with round holes 2.4 mm. in diameter. The method of investigation is very rough; only the part of the chewed material remaining in the strainer has been preserved. The weight of the weighed fraction which remains in the strainer was then calculated in per cent of the undried mass, i. e. 5 g.

From a practical viewpoint it may be objected that the test materials used in the investigations described must have been difficult to chew for persons with poor teeth. After all it is first and foremost the masticatory powers of such persons that there is special reason for testing. It is further of importance that the test material should be standardized, homogeneous and indissoluble in saliva. It is probably doubtful whether hazel-nut, cocoanut, Brazil nut and almond are, in the respects mentioned above, what is required in a test material. It is likely that the material, at all events to some extent, changes its character when kept due to possible drying.

For the straining, most investigators have used a network of four sizes, two of which had meshes so small that only very tiny particles could get through. When investigating the effect of mastication efforts should be made as far as possible to base the investigation on the fact that it is the power of the jaws and the teeth to decimate ordinary food which is of interest. Consequently, the above choice of test material and of strainers has not been appropriate. Too fine strainers have been used.

The method of sorting out the chewed portions into different fractions has not been standardized. The drying of the fractions gives no sure guarantee that the different-sized particles are dried to the same extent from case to case. The separate fractions remaining after the drying do not weigh much, and the values obtained after weighing are not made more reliable by the fact that this is done with precision scales to the fourth decimal place, as the straining method is probably very uncertain.

Summing up, it should thus be possible to say that, up to now, not very suitable test materials have been used, and that the methods which have been worked out have been unsatisfactory and must have given very unsure values. These judgments are based on a general discussion of the methods. No investigator

has made an analysis of the standard error of measurement, and there are therefore no exact data as to their reliability. This being so, it is desirable both to work out, if possible, a more reliable method, and also to investigate the limits of error for the method which may finally be achieved.

A short account will now be given of the results obtained by the above-mentioned authors in their investigations with the methods described into the masticatory powers of a number of persons.

The results obtained.

As has already been said, CHRISTIANSEN, 1922, tried to investigate whether complete prostheses, mounted according to the articulation method, function better in mastication than those mounted according to the occlusion method. His material consists of 7 persons with complete prosthesis of each kind. The author submits figures of the distribution into different fractions in articulation prosthesis and occlusion prosthesis, and draws the conclusion that the articulation prosthesis functions better. Actually, there are no criteria for judging whether the difference in his material is a true one or has arisen at random. Seeing that, as has been said before, the method must be fairly uncertain, and as he investigated only 7 persons, it is very possible, and even probable, that the moderate differences he found are purely chance ones. It is therefore impossible to venture a definite statement on the basis of the published material. Christiansen has also investigated the masticatory powers in 10 persons with complete prostheses, mounted in such a way that the teeth of the one side were set in articulation and those of the other side in occlusion. The aim with this was that the patient should chew exclusively with the articulation side on the one occasion, and with the occlusion side on the second. The results from this experimental series show, on the whole, smaller fractions on the coarsest strainer and higher fractions on the finer strainers in chewing with the articulation side. In a number of cases the difference is not marked; this the author considers due to the fact that the teeth on the occlusion side happened to be set comparatively correctly. The author has also compared the effect of mastication in several patients with defective sets of teeth with and without artificial replacement, and, further,

4 patients with complete sets and 4 where they were defective. No statistical analysis of the figures obtained by the chewing tests has been made. The author only publishes the figures and lets them speak for themselves.

An investigation, also concerning a comparison between complete prostheses of different construction, was made by BALTERS in 1928. First, 4 toothless patients with complete sets of artificial teeth were investigated for the effect of mastication. In so doing the author got extremely varying values, and came on this account to the conclusion that even a comparison between the masticatory powers in the same patient provided with two different prostheses is not possible with the methods used.

The author decided to compare the masticatory affect of complete prostheses mounted both with and without regard to the individual path of the condyles. Two patients were equipped with prostheses where the teeth in the articulator had been set up and ground in with consideration paid to the path of the condyles of the patient. After allowing the patient time to get used to the set, the masticatory effect was investigated. The same prosthesis was put into the articulator again and the teeth ground in with the path of the condyles in horizontal position and with the same height for the bite. After this the masticatory effect was again tested.

By arranging the experiments in this way, the same conditions were obtained with the two chewing tests except for the factor which the author wished to test. He found no difference in the masticatory effect »outside the normal range of variation», but at the same time he stresses the fact that the results do not prove it unnecessary to take into account the slope of the condyles when making complete prostheses.

Compared with Christiansen, Balters is remarkably chary with his conclusions and has his eyes open to the uncertainties which attend the method of testing.

In a later work BALTERS, 1930, has investigated the masticatory powers in a patient who was made to chew successively with four complete prostheses mounted with the same height of the bite, the same base and the same front teeth, but with grinding teeth of different construction and material. Here the author considered he found marked differences in masticatory powers between the different prostheses. However, it is hardly possible to reach any definite conclusion on the basis of the figures Bal-

ters submitted, since no computation has been made of the standard error of the testing.

How effectively a complete prosthesis functions depends on several factors, as e. g., the height and firmness of the crista, the way the jaws are placed in relation to one another, the articulation of the teeth, and so on. A number of experiences have been empirically collected as to how a prosthesis is to be constructed to function satisfactorily. It is, however, the patient's own experiences which ultimately decide whether the prosthesis is to be considered »satisfactory». Now, when judging his prosthesis, the patient has as a rule only slight criteria to go on, and seldom has the chance to compare different models. Even if the information he gives has a certain value, it would be of advantage to get in addition an objective gauge of the effectivity of the prosthesis by means of a test of the masticatory effect. We could then, as Balters tried, also go a step further and make prostheses identical save in the one or other respect, and thus, by a systematic investigation, find out the relation different constructions bear to one another as far as function is concerned.

The effect of anomalies in the set of teeth on the masticatory powers has not been studied in much detail. It has been assumed without any definite grounds that practically every clear anomaly means a decline of these powers. Juul, 1932, has taken up this problem for investigation and collected a material consisting of 27 children with normal occlusion and 26 with abnormal occlusion. The children, who all had complete sets of teeth, were from 11—17 years of age.

The author compares the effect of mastication, expressed in per cent of the 4 different fractions, in children with normal and abnormal occlusion, and finds that the latter have larger fractions on the coarsest strainer. For the three finer strainers, the situation is reversed. The results show that the masticatory powers in children with anomalous sets of teeth are on an average worse than in those with normal sets of teeth. It is, however, difficult to estimate the results obtained, since no more detailed information is given as to the degree of dental anomalies. Further, the author has not calculated the standard error of the tests, so that no closer analysis of the figures is possible.

A work of Ascher, 1938, deals with a material of adults, some with complete and some with defective sets of teeth. The author presents 68 tables with figures of chewing tests, but the tables

do not show how far the tests were carried out by the same person; nor is the number of investigated subjects given.

The investigation material is divided according to the number of teeth into three groups. Under the first group come the complete sets, and, as well, such as have an unbroken row of teeth only on the one side. Characteristic for this group is the fact that the fraction on the coarsest strainer, is very small and as a rule equals nought. The sum of the fractions in the two finer strainers is larger than those in the two coarser ones. Under the second group come the slightly defective sets of teeth with up to 6 mastication units missing (one mastication unit means according to Ascher, one molar pair in articulation position, and a half unit a pre-molar pair or incisor pair in articulation position). The difference between this group and the first one is small, and it is also characterized by the sum of the finer fractions being greater than that of the coarser. The third group with more than 6 mastication units missing shows no »correlation» between the masticatory effect and the number of mastication units. With 30 chews, the coarser fractions preponderate, and it is only after 80 chews that there is a levelling out to the advantage of the finer fractions. The author comes to the conclusion that a loss of more than 6 mastication units indicates prosthetic replacement.

It is, however, impossible to judge how far the conclusions which the author considers himself able to draw are motivated by the numerical result submitted. It has not been statistically treated, and the figures vary not inconsiderably. A statistical treatment is impossible, on account of missing data as to how far the tests have been made by the same or different persons; nor is it known to what extent the author may possibly have wanted to demonstrate results by submitting selected examples. The figures given naturally point in the direction given by the author, without our being able to consider his conclusions to be proved.

Gelman, 1932, has carried out about 250 masticatory function tests, of which a small number are described in his work. As has already been said, the author had his test subjects chew for a certain period. One table shows that, of 7 persons, two needed to chew for 30 seconds and the rest for 50 seconds for practically no remains of the chewed material to remain in the only strainer he used. The 'optimal' chewing period was set at 50 seconds, and this time was chosen as a unit for the chewing tests.

The author investigated 38 persons, for whom he gives figures for masticatory effect and the number of articulating pairs of teeth. According to the tables, it appears that 4 investigated persons with, on an average, 12.5 articulating pairs of teeth have a mean figure of 96.4 per cent for the part of the test material passing the strainer. It further appears that 17 persons with, on an average, 9.8 articulating pairs had a corresponding figure of 68.7 per cent, and the mean for 13 persons with an average of 7 articulating pairs was 54.1 per cent. It is finally seen that 4 persons with an average of 3.2 articulating pairs of teeth had a mean of 17.9 per cent.

The author finds that a loss of 6—9 articulating pairs of teeth — i. e. on an average, 7 pairs — decrease the masticatory powers by half, which state he considers to give a fairly unsatisfactory masticatory effect.

There is no possibility of determining how far the differences found by the author have arisen at random, since he submits no figures for the individual cases and has not made calculations about the standard error. For the rest, he sets up a strange formula for the effectivity of the chewing, which includes not only the period of mastication and the amount of material chewed, but also a factor characterized as the psychosomatic condition of the test subject and 'die Lebensverhältnisse'.

It may be advanced, by way of *summary,* that investigations hitherto carried out indicate that it should be possible by chewing tests to measure the masticatory effect in persons with sets of teeth of different character. Meanwhile the methods hitherto used must be regarded as very unsure, but it should be possible to improve them. The investigations which have been carried out as to how different people chew, comprise comparatively small and selected materials, which have not been submitted to any statistical analysis. For this reason, no clear picture of the masticatory effect under different conditions has as yet been obtained. In summarizing the literature Sognnaes 1941 says that the studies on masticatory efficiency »have not been extensive enough, nor have they been sufficiently well controlled to allow any definite conclusions».

The first part of this investigation concerns method. An attempt is made to work out a method suitable for determining the masticatory effect. Different materials have been tried out to ascertain their suitability as test materials. An apparatus for straining has been constructed, and special methods of computing the effect of mastication by reducing the test material have been worked out. The author has arrived at a standardized method which should be tolerably exact, and at the same time can be used for mass investigations.

In the second part this method is used for testing the masticatory effect in children, grown-up persons, old people and persons with full prostheses, of both sexes. This material has been statistically analysed, firstly in regard to the extent of the defects in the teeth and the number of contacts between the teeth. Secondly, the chewing has been investigated and the number of chews in persons differing as to age, sex and the character of their sets of teeth, has been statistically analysed. The third and main point of the investigation is the masticatory effect in varying conditions of the teeth and in groups of different age and sex. In particular the variability and factors which cause the variability are investigated. Finally the masticatory effect in persons with full prostheses is compared with the effect of mastication in persons with teeth of their own.

In the statistical analysis only elementary methods have been employed. The reader is referred to any textbook, for instance: Gunnar Dahlberg: Statistical Methods for Medical and Biological Students (1940).

Part I.

Methods of a mastication test

Chapter 2.

Theoretical discussion of the requirements in a mastication test.

As appears from the survey of the literature, there is at present no satisfactory method of gauging the function of the teeth in mastication. A procedure is required which is standardized and analysed as to its reliability. Not until a satisfactory test has been arrived at will it be possible to investigate the masticatory powers in a complete and in a more or less defective set of teeth, and get something to go on when judging both the need and the effect of a prosthesis. Only when it can be determined how far an incomplete number of teeth means a decrease in the masticatory powers and thus not so good reduction of the food, can further investigation be made into the importance of a deficient set of teeth for digestion, the general state of health, and the like.

A test method for investigating the masticatory powers calls first and foremost for a suitable material to chew. It is, further, necessary to work out a method to establish how effectively the chewing is completed. We shall begin by discussing the question of a suitable material, and then go on to determining the degree of its mastication.

Materials for a mastication test.

At a primitive stage of culture, when the main food substances are either raw or very little prepared, the teeth play a very much more important part in mastication than is the case in civilized conditions. Our usual food is chosen and prepared in such a way that the demands we have on the powers of our teeth are really very small.

The food substances included in a normal diet can be roughly divided up according to their consistency into the following groups:

1) *soft:*
e. g. butter, cheese, eggs, minced meat, fish, soft bread, boiled potatoes, boiled root-crops, stewed fruit;

2) *firm — tough:*
e. g. beef, pork, liver, kidneys;

3) *firm — brittle:*
e. g. hard bread (rye-vita), biscuits, rusks;

4) *firm:*
e. g. raw vegetables, raw root-crops, raw fruit.

For persons with few teeth or complete prostheses, some of these substances are difficult or impossible to chew. Most difficulty is probably encountered in tough boiled beef. Persons with poor teeth often cut the meat into small pieces and swallow it down without chewing at all. On the other hand, the chewing of raw fruit and hard bread, for example, would seem, according to reports from the patients, to offer less difficulties, provided that the mouthfuls are not too big.

As regards the nature of normal food, a tabulation has been made, based on reports communicated by Kungl. Socialstyrelsen (Royal Social Board) of the consumption of foodstuffs in normal Swedish households for the fourth quarter of the year 1940. It is found that firm and tough food substances (meat etc. of different kinds) constitute about 4.5 per cent, firm substances about 5 per cent and firm and brittle substances 2 per cent. The main part of the substances normally consumed belong to the group of soft foods, namely 88.5 per cent.

When choosing material for a mastication test, the following theoretical viewpoints should in the first place be observed.

I. The material for chewing should be of a character to resemble ordinary food to some extent. It should not be so easy to chew that persons with practically no teeth can press it into bits with their tongue and alveolar processes, but it must not either be so difficult to chew as to disable persons with extremely bad sets of teeth from making the test. The material should be chosen within these limits.

II. The material for chewing should not swell, or dissolve in water or saliva.

III. During chewing, the material should be reduced in such a way that it is possible to establish the degree of reduction. When being crushed, it must not be divided along preformed directions of cleavage, as is the case with hard bread; nor must it stick together, as with chewing-gum.

From a practical point of view, it is necessary that the material is standardizable, will keep for more than a very short period and has a pleasant or at any rate an indifferent taste.

As has been said already, boiled beef is unduly difficult to chew for persons with insufficient teeth, and does not in other respects agree with the demands set. Liver, kidneys or such are conceivable materials for chewing, though hardly suitable — for one thing because they have a somewhat varying character and are thus difficult to standardize.

The hard-boiled white of a hen's egg answers most of the demands which have been set, though, however hard it is boiled, it is of so soft a consistency that it can be chewed even by toothless people.

Of the vegetable food substances, raw carrot may be considered just difficult enough to chew. Carrot does not break up along preformed directions of cleavage; it is, however, somewhat soluble and also swells in water. The edges of the chewed particles are not sharp, so that a sorting into different sizes will be uncertain. There is a difference in consistency between the fresh and the stored carrot, and this means that one cannot have access to a constant material if the investigation is to spread over some time.

Examples of non-food substances, which are possible as test material, are synthetic rubber, indiarubber and gelatin, hardened by formalin.

Synthetic rubber of the kind used by draughtsmen differs from usual sorts of rubber by virtue of its porous nature. The material fulfils the theoretical demands which have been drawn up, but it has an unpleasant taste and gives, when chewed, a choking sense of dryness.[1]

[1] Only a small quantity has been obtainable for testing purposes.

For comparison with synthetic rubber, indiarubber of soft, porous character can also be tested. This can be reduced to small pieces by people with good sets of teeth, though not completely so, since the chewed particles have a tendency to cohere. Further, indiarubber can be chewed by persons with bad sets of teeth only with the greatest difficulty or not at all.

One would rather expect gelatin hardened by formalin to be best able to answer the demands for a suitable material for mastication. The food substances to which this material can, with regard to its consistency, most be likened are liver boiled hard or boiled veal gristle. (This latter is not, of course, reckoned as a foodstuff but is, alas, not infrequently included as an ingredient in cooked veal.) Gelatin can vary as regards gelatinous content, and it is therefore possible to test different consistencies. By hardening it in formalin, the mass is changed, so that it no longer dissolves in water. There is no very precise knowledge as to the effect of the formaldehyde on gelatin at hardening. The water is combined to the gelatin micelle. A number of water molecules are absorbed on the surface of the micelle and others are enclosed between the micelles. It has been assumed that the effect of the formaldehyde in hardening would strengthen the 'cross communications' in the network of polypeptide chains forming gelatin micelles, which means that the gelatin cannot be dissolved in water or the water molecules penetrate between the micelles.

Subdivision of the test portion.

In empirical testing of the material, as in making the chewing test, the degree to which the chewed portion has been reduced must be determined. The most feasible procedure would seem to be to follow earlier investigators and divide up the chewed mass into a suitable number of fractions, where each fraction can be thought to contain particles of about the same size. A further concern is to determine the quantity of particles within each fraction. How suitably to perform the fractionation depends on the character of the test material. When the chewed mass does not contain water, as is the case with synthetic rubber or indiarubber, for example, the fractions may be dry-sifted and weighed. If, on the other hand, the material is one containing water, e. g. carrot or gelatin hardened by formalin, mastication gives particles which cannot be sorted by means of dry-sifting,

for fear of drying up and because of their tendency to stick together. Under such circumstances, the straining must be done in water.

In the investigation presented here, the latter method has been used. When determining the number of strainers and the size of the holes, it is advisable to choose these according to the size of the particles present in a test portion; this latter should be divided up into enough fractions for each one of them to be comparatively small. Not until this has been done can it be justifiably assumed that the particles in one fraction are of an order of magnitude lying between the holes in the two strainers limiting the fraction. It is advisable to take too many rather than too few strainers, so that relatively small and numerous fractions are obtained. It is always possible in the statistical treatment to put the fractions together, if necessary, but they cannot on the other hand be divided up further, if found too few. Previous investigators have been content with a few fractions (at most four), and a finer division of the portion for chewing is surely desirable.

Running water must be used in straining to prevent larger particles from getting lodged in the holes and hindering the passage of smaller ones. The running water should have a rotating component, so that the particles are moved about over the holes, and at the same time a downward component, so that they are sucked through. An irregularly shaped particle with different sizes in different planes will in this way have repeated possibilities for getting through.

To get comparable results from straining, the method must be standardized as regards the amount of water passing through the apparatus per time unit. Standardization implies that the time of straining and the water pressure must both be constant.

Different ways can be taken of determining the *size of the fractions*. Thus, it is possible to get an idea of the particles' distribution in the test portion by weighing the different fractions separately; any water must, of course, first be removed. If the test material contains water, there is a risk that the actual particles, too, will dry up. There is obviously difficulty in standardizing the drying process so that water is removed to the same extent in different fractions. The method has the further disadvantage that drying and weighing waste time. This procedure therefore seems very little suited to a mass investigation.

Instead of weighing the different fractions, it is, however, possible to count the number of particles which remained in the less fine and coarse strainers. Such a count does not take much time and should give a reliable result. The difficulties do not begin until the counting of the particles in the finer strainers. On this account, the finer fractions can suitably be determined by measuring the volume after sedimentation of the particles in graduated glass tubes. (This method has actually been used.) This method has the advantage of weighing in that the size of the different fractions is determined without the particles being exposed to air-drying. The method is quick, and should be suitable for use in mass investigations.

All the same, both methods have the drawback that the results consist of a series of figures for the sizes of the different fractions. The figures show that, if fractions with small particles are large and fractions with large particles are small, the reduction is more complete than if the opposite is the case. Nevertheless, it is difficult to form from the figure series obtained a clear idea of the degree of the test portion's reduction. The figures are difficult to survey as a whole, and a simple expression for the degree of reduction is desired.

Now the act of chewing means that the portion is reduced so as to give a larger total surface than in its original state. The enlargement of the surface per volume unit has the advantage that the digestive juices have better play. It is in this way that the chewing of food is of importance for the digestion. In principle, it should therefore be reasonable to try and get a simple gauge of the effectivity of mastication by calculating the total surface of the fractions and relating them to the volume of the test portion. In this way a *mastication coefficient* is obtained which gives a simple expression for the degree of reduction, and which has a close connection to the physiological problem in question. An assumption now readily presenting itself is that the particles are on an average regular polyhedrons. On the basis of different assumptions it is possible, when the number of the particles in the fractions is known, to calculate the total volume and test if it agrees with the known volume of the test portion. It is further possible to calculate the total surface and then get the mastication coefficient — i. e. the surface area per volume unit.

It can now be assumed that the particles in the fractions on an average correspond to cubes, mixed with shapes of larger

volume more or less spherical, and also with shapes of less volume corresponding to octahedrons or the like. In reality, of course, the question is, throughout, one of particles with very irregular shape. It can further be assumed that the particles correspond on an average to octahedrons, and we can seek to prove this.

Let us, therefore, assume that the particles are, on an average, in the form of cubes and that the measurement of their side diagonal lies between the diameter of the holes in strainers that have been passed through and those that have not. If this mean diameter is called d, the side of the cube is obtained in the expression $\frac{d}{\sqrt{2}}$. From the side of the cube we get its volume from the expression $\frac{d^3}{2\sqrt{2}}$, and the volume of the fraction from the expression $N\frac{d^3}{2\sqrt{2}}$, where N is the number of particles in the fraction. We further assume that the particles have on the average, the shape of octahedrons, and can then in analogous wise calculate their volume from the formula $2\frac{B\cdot h}{3}$, where B is the basal surface of the pyramid and h is the height. The diagonal of the octahedron's base is the same as the side diagonal of the cube, so that the side of the octahedron is obtained from the expression $\frac{d}{\sqrt{2}}$, the basal surface being $\frac{d^2}{2}$ and the height in the one pyramid $\frac{d}{2}$; the octahedron's volume will be $\frac{d^3}{6}$. The volume of the last fractions can be calculated after it has been determined by sedimentation of the particles in graduated glass tubes. It is then necessary, however, to change these volumes into number of particles, which can be done by determining the number of particles per volume unit. The volume of the fraction is then calculated from the formula $vn\frac{d^3}{6}$, where $v =$ the volume obtained through sedimentation and $n =$ the number of particles per sedimented volume unit. (For cubes of course the corresponding formula is $vn\frac{d^3}{2\sqrt{2}}$.)

The surface of the test portion can now also be calculated in the same way. If we assume that the particles are cubical, we get the surface of the fraction by multiplying the number of particles by 3 d^2 (the side of the cube is $\frac{d}{\sqrt{2}}$, as before). The surface of an octahedron with the same base diagonal as the side diagonal of the cube is got from the formula $d^2\sqrt{3}$, if we proceed from the same assumptions as in the determination of the volumes. For fractions with volumes determined by sedimentation, the formula $vnd^2\sqrt{3}$ is used, where the signs mean the same as above. For cubes the formula is $vn3d^2$.

The following pages will give an account of the investigations made with regard to different chewing material and different methods of dividing up the test portions by straining into different fractions etc. to the end of achieving a standard method for mass investigations. Here the author will only anticipate by saying that the method finally preferred is one based on a division of the test portion by means of straining into 10 fractions. In fractions 4—10 the number of particles are counted, and in fractions 1—3 (the finest ones) the mass of particles is determined by sedimentation in graduated glass tubes. A determination of particles per c. cm. is further made in the sedimented fractions. Finally, the surface and volume of the test portion are determined under the assumption that the particles in fractions 4—10 corresponded on an average to cubes, and those in fractions 1—3 to octahedrons. The mastication coefficient — i. e. surface area per c. cm. — is reckoned out from the calculated surface and volume. In Chapter 6, the tenability of these assumptions will be tested in more detail on the basis of empirical investigations. These data have been given in advance, as the reader needs them to be able to follow the account of what is now coming.

Chapter 3.

Investigation of different test materials.

In the foregoing chapters different materials have been discussed with regard to their suitability in mastication tests. Even if gelatin hardened by formalin would seem in theory to be most suitable, it is necessary for more definite conclusions to test this empirically.

A small number of people have been made to chew fixed portions, one after the other, of all the test materials discussed above. The test subjects consisted of conscripts, half of which had 'extremely good' sets of teeth, and half 'bad'.[2] At the tests, each person on one and the same occasion chewed in turn pieces of gelatin hardened by formalin, hard-boiled white of hen's egg, raw carrot, synthetic rubber and indiarubber. There was one series of portions chewed until they felt ready to be swallowed, and two series where the portions were chewed 40 times. The results of tests with different materials have been compared with regard to the difficulty in reducing the material to small pieces, and also with regard to errors of measurement in re-straining the test portion.

Average values for the size of the fractions in the different materials are given in Table 1.

Comparing the mean sizes of the fractions after 40 chews from test subjects with good and poor sets of teeth, we find that the degree of reduction in good sets is greater than in poor ones. The fractions in good sets are, compared with the others, greater for the strainers 1—4 and smaller for strainers 6—10. The differences in reduction between good and poor sets of teeth are most outstanding in the fractions with the largest and the smallest particles. As it is difficult to get a general survey of the average

[2] With regard to the limits of good and bad sets of teeth respectively, cf. Chap. 11.

TABLE 1.

Distribution of tests on different fractions (means). For the fractions 1—3 the volume is given in c. cm., for the fractions 4—10 in number of particles. The number of the fraction indicates the diameter of the holes in the strainer in mm.

Fraction	Gelatin 10 %	Gelatin 15 %	Gelatin 20 %	Carrot	White of egg	Synthetic rubber	India-rubber
	Extremely good set of teeth: mastication at discretion.						
1	1.6	2.2	2.5	1.8	2.2	3.3	0.18
2	3.2	4.1	4.5	2.8	2.6	3.7	0.37
3	4.0	4.4	4.6	3.3	2.9	3.3	0.55
4	53.2	60.0	59.8	35.6	33.8	32.5	11.1
5	27.6	26.7	25.2	22.8	19.5	16.5	11.1
6	11.4	11.3	10.4	10.7	10.0	7.8	10.2
7	5.0	5.9	4.5	4.9	5.8	4.2	9.2
8	2.2	2.2	2.2	2.6	3.7	1.9	6.3
9	0.78	0.78	0.73	0.54	2.0	0.79	4.4
10	0.46	0.46	0.78	0.63	2.8	0.94	7.2
	$n = 41$	$n = 41$	$n = 41$	$n = 41$	$n = 41$	$n = 33$	$n = 11$
	Bad set of teeth: mastication at discretion.						
1	0.44	0.63	0.82	0.77	1.5	1.6	0.08
2	1.0	1.4	1.6	1.4	1.8	1.9	0.14
3	1.8	2.1	2.4	1.7	2.0	2.1	0.18
4	34.0	36.5	42.2	21.2	25.9	34.3	4.7
5	24.7	26.8	29.2	17.2	16.9	20.4	4.1
6	15.9	16.7	18.0	12.7	9.9	12.5	4.2
7	10.8	9.9	11.1	8.7	7.0	8.2	4.0
8	6.0	5.8	5.9	5.5	4.7	4.2	4.3
9	2.5	3.1	2.5	2.5	2.8	2.2	3.8
10	2.9	2.5	2.4	2.6	4.2	2.0	11.4
	$n = 42$	$n = 42$	$n = 42$	$n = 42$	$n = 42$	$n = 36$	$n = 12$
	Extremely good set of teeth: 40 chews.						
1	1.9	2.0	2.3	2.1	3.7	3.2	—
2	3.5	3.9	4.0	3.0	4.2	3.7	—
3	4.4	4.4	4.3	3.4	3.8	3.1	—
4	58.0	60.0	57.5	38.1	40.7	36.7	—
5	26.6	27.1	26.9	22.1	19.5	17.7	—
6	11.3	10.7	12.1	11.4	6.9	6.7	—
7	4.6	5.2	6.1	4.6	2.9	3.6	—
8	2.2	2.9	4.2	2.4	0.94	1.7	—
9	0.77	0.98	0.94	0.82	0.41	0.48	—
10	0.56	0.56	0.97	0.54	0.17	0.83	—
	$n = 82$	$n = 82$	$n = 82$	$n = 82$	$n = 81$	$n = 46$	

Table 1 (cont.).

Fraction	Gelatin 10 %	Gelatin 15 %	Gelatin 20 %	Carrot	White of egg	Synthetic rubber	India-rubber
			Bad set of teeth: 40 chews.				
1	0.62	0.66	0.68	0.72	2.3	1.1	—
2	1.4	1.3	1.4	1.2	2.7	1.4	—
3	2.2	2.0	2.0	1.5	3.0	1.7	—
4	37.6	35.3	33.5	17.0	38.7	26.1	—
5	26.6	24.9	25.9	14.9	22.6	18.1	—
6	16.8	15.9	16.1	11.5	12.3	12.2	—
7	10.0	10.5	10.2	8.9	6.5	7.9	—
8	5.4	6.3	5.9	5.6	3.6	4.9	—
9	2.8	2.8	3.5	3.2	1.5	2.5	—
10	2.0	3.2	3.9	5.3	0.97	2.8	—
	$n = 84$	$n = 84$	$n = 84$	$n = 84$	$n = 82$	$n = 51$	

reduction of the different materials from the figure series in the tables, there can hardly by any reason for commenting on these latter in more detail. The tables over the different material's degree of reduction are only given as a check, as subsequent calculations of volume, surface and mastication coefficient are based on them.

The average values for surface, volume and mastication coefficient calculated according to the method used in the investigation are given in Table 2.

The figures in the table show that, on the whole, white of egg and synthetic rubber are more easily reduced than any other of the tested materials. Carrot and formalin-hardened gelatin of varying gelatinous content agree well in reduction both for good and bad sets of teeth, and both when chewed at discretion as after 40 chews. When comparing the mastication coefficient for formalin-hardened gelatin, it is found that the higher the gelatinous content, the easier it seems to be to reduce the test portion to small pieces. With 20 per cent gelatin, the portion becomes harder but at the same time more brittle, which latter quality probably explains a higher mastication coefficient than might have been expected. The difference is nevertheless small. It can further be seen from the figures in the table that the mastication coefficient for indiarubber is considerably lower than for the other materials, a circumstance naturally due to the fact that indiarubber is very hard to chew.

TABLE 2.

Calculated surface, volume and surface area per c. cm. (mastication coefficient) for tests of different materials. The figures have been computed from the figures in Table 1. M. C. = mastication coefficient, sq. cm./c. cm.

Material	Surface, sq. cm.	Volume, c. cm.	M. C.
Extremely good set of teeth: Unrestricted number of chews.			
Gelatin 10 %	212.99	9.157	23.3
» 15 %	247.47	10.082	24.5
» 20 %	258.67	10.106	25.6
Carrot	188.21	7.971	23.6
White of egg	200.01	9.247	21.6
Synthetic rubber	223.27	7.983	28.0
Indiarubber	109.55	9.373	11.7
Bad set of teeth: Unrestricted number of chews.			
Gelatin 10 %	154.65	10.093	15.3
» 15 %	170.20	10.515	16.2
» 20 %	187.20	11.125	16.8
Carrot	141.06	8.567	16.5
White of egg	169.21	9.193	18.4
Synthetic rubber	177.86	9.059	19.6
Indiarubber	81.70	8.285	9.9
Extremely good set of teeth: 40 chews.			
Gelatin 10 %	228.28	9.543	23.9
» 15 %	241.52	10.058	24.0
» 20 %	252.75	10.764	23.5
Carrot	200.40	8.242	24.3
White of egg	242.27	7.966	30.4
Synthetic rubber	217.23	7.667	28.3
Bad set of teeth: 40 chews.			
Gelatin 10 %	167.71	10.193	16.5
» 15 %	168.70	10.612	15.9
» 20 %	174.11	11.098	15.7
Carrot	142.05	9.422	15.1
White of egg	209.57	9.125	23.0
Synthetic rubber	153.52	8.701	17.6

Finally, a smaller number of persons with good and poor sets of teeth have, in ways previously given, chewed the above tested materials, and each portion was fractionated twice. The purpose of the investigation was to compare the different materials with regard to the possibility of obtaining accordant values for the

same fraction by re-straining the test portion. The absolute and the percentual standard error for the strained fractions have been calculated from the differences. Some of the fractions have been made into one, as shown by the tables, to give more general figures. (See Table 3.)

The figures in the table show that both the values for the absolute standard error of measurement and also the variation coefficients (= standard error in per cent of the fraction's mean) are, for a good set of teeth, higher for carrot and white of egg compared with the corresponding values for gelatin. A comparison between gelatins of different concentrations reveals less pronounced differences. A comparison with corresponding figures for poor sets of teeth shows considerably lower standard errors. The differences in the standard error between different materials also become less, which may be due to the fact that reduction is less effective with poor sets of teeth. In spite of the amalgamation of some fractions, however, it is difficult to get a general survey of the figures. For this reason, Table 4 gives standard errors obtained from differences between calculated mastication coefficients.

Thus, mastication coefficients have been calculated for the two strainings of one and the same test portion, and in this table the coefficients have also been calculated for two consecutive tests with exactly 40 chews. From the differences, the standard error for a single determination has been calculated. The figures show clearly that 15 per cent gelatin gives throughout a smaller standard error than carrot, white of egg and synthetic rubber; this applies both to the absolute standard error and to the percentual error. An exception is synthetic rubber with a good set of teeth, when this material seems to be about as good as gelatin; it has, however, not been possible to get enough of the former for more thorough testing. Although the number of accomplished tests is not great, the figures nonetheless seem to indicate fairly definitely that 15 per cent gelatin should offer certain advantages.

Summing up, it may be said that the investigation verifies on the whole the assertions made at the theoretical discussion of the different materials. White of egg proves to be too easy to chew. This is, however, also true of synthetic rubber — a rather unexpected discovery, since the impression of a harder material is given during mastication. Carrot and gelatin seem about the

TABLE 3.

Standard error of measurement of a single determination, calculated on differences between two strainings of the same test with mastication at discretion and for both extremely good and bad sets of teeth. The standard error of measurement is calculated as standard deviation (= σ), of a single determination on the one hand, as variation coefficient (= V, i. e. in per cent of the pertaining mean, on the other. M = mean of the standard errors of the different fractions. n = number of persons.

Material	Standard error of measurement in straining; mastication at discretion						
	n		Fraction				M
			1—3	4—5	6—7	8—10	
Extremely good set of teeth.							
Gelatin 10 %	16	σ	0.302	5.62	1.25	0.637	1.95
		V	3.7	7.1	8.1	16.1	8.8
» 15 %	16	σ	0.158	3.96	1.16	0.530	1.45
		V	1.6	5.0	7.1	13.8	6.9
» 20 %	16	σ	0.350	8.53	1.57	0.707	2.79
		V	3.2	10.5	10.7	17.4	10.5
Carrot	16	σ	0.408	4.96	2.86	1.22	2.36
		V	4.0	7.5	15.6	25.8	13.2
White of egg	16	σ	0.664	4.68	2.72	1.58	2.41
		V	8.7	7.8	14.2	13.8	11.1
Synthetic rubber	16	σ	0.504	2.25	1.89	0.500	1.29
		V	5.2	4.9	19.1	28.6	14.5
Bad set of teeth.							
Gelatin 10 %	16	σ	0.167	3.19	1.85	1.19	1.60
		V	6.6	5.8	6.8	9.6	7.2
» 15 %	16	σ	0.178	5.85	2.14	1.50	2.42
		V	5.6	9.5	7.5	12.4	8.8
» 20 %	16	σ	0.228	4.03	1.75	0.901	1.73
		V	5.7	5.5	5.7	7.8	6.2
Carrot	16	σ	0.321	5.80	3.68	1.80	2.90
		V	7.7	13.3	14.7	16.1	13.0
White of egg	16	σ	0.273	3.81	1.70	1.00	1.70
		V	5.4	9.0	9.8	7.9	8.0
Synthetic rubber	16	σ	0.179	2.20	1.80	0.285	1.12
		V	4.2	4.2	9.2	4.2	5.5

TABLE 4.

Standard error of measurement of a single determination of the mastication coefficient, calculated on a series of differences between double strainings of the same test, and on double mastication tests (with 40 chews in each), carried out on a series of persons with both extremely good and bad sets of teeth. The standard error of measurement is given as standard deviation ($= \sigma$) of a single determination, on the one hand, as variation coefficient ($= V$), i. e. in per cent of the pertaining mean, on the other. n = number of persons.

Material	Standard error of measurement in straining (mastication at discretion)			Standard error of measurement in straining (40 chews)		
	n	σ	V	n	σ	V
Extremely good set of teeth.						
Gelatin 15 %	16	0.045	1.8	16	0.262	11.2
Carrot	16	0.097	3.9	16	0.350	13.6
White of egg	16	0.045	2.3	16	0.363	12.7
Synth. rubb.	16	0.073	2.4	13	0.263	8.2
Bad set of teeth.						
Gelatin 15 %	16	0.032	2.1	16	0.062	4.2
Carrot	16	0.075	4.5	16	0.211	14.7
White of egg	16	0.054	3.0	16	0.397	17.9
Synth. rubb.	16	0.044	2.4	15	0.110	6.5

same as regards chewing difficulty, but carrot (like white of egg) has a rather large error of measurement in straining, which is one of the reasons why it is less suitable. It does not matter very much which concentration of gelatin is chosen, as they all work out much the same when chewed. The author has decided on 15 per cent gelatin, as this content seems to be more suitable as regards consistency than the two others.

Chapter 4.

The preparation of test portions for chewing.

On the basis of the analysis which has been carried out on different materials 15 per cent formalin-hardened gelatin has been chosen as test material for subsequent investigations.

The portions were made by casting the prepared gelatin solution into rods, which were cut into pieces, hardened by formalin, and washed.

Gelatin leaf contains between 12—17 per cent of water, but this variation in content is probably of no importance. When making the gelatin solution, colouring matter and 5 per cent barium sulphate were added. It is difficult to distinguish and count uncoloured gelatin particles, on account of their transparency, and this is one of the reasons why barium sulphate is added: it makes the portions white and rather like sticks of shaving cream to look at. Anyhow, they do not look attractive to chew, so, to get over this, the solution is stained with fuchsin; this turns the finished portions pale pink like a Christmas sweet. There has also been another reason, though less important, for the addition of barium sulphate. As this salt has a high specific gravity, the particles get somewhat heavier from the addition, and this may prove of advantage in straining.

The gelatin solution was prepared as follows. The amount of water was measured out and coloured with a small quantity of fuchsin, after which all the gelatin powder was added at once. The mixture was then heated over a water-bath, stirring constantly, until the gelatin melted, care being taken that the temperature did not exceed 70—80° C. When all the gelatin had melted, barium sulphate was added; the latter should first be mixed with a little of the solution to form a thick paste and stirred until smooth. Still being stirred the finished mixture of gelatin + barium sulphate was poured into a number of metal containers all the same size. The heavy barium sulphate tends

to sink to the bottom, so one wants the solution to set as soon as possible; to this end, the metal containers are stood in water while being filled.

When the solution has set, the next question is how to get it out without damaging it. Now, the metal container consists of two cylinders, an outer and an inner one, the latter divided longitudinally into two halves. With a simple screwing device, the inner cylinder can be pushed up and taken apart. It goes without saying, that all the cylinders should be of exactly the same size, so that any of the inner ones fits any of the outer ones.

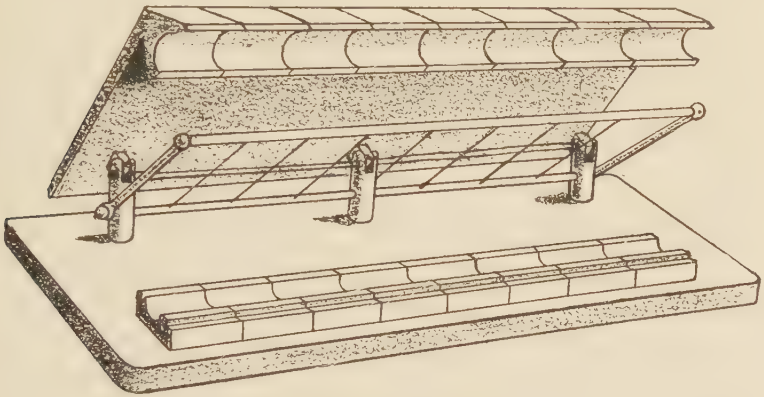

Fig. 1. The cutting machine.

Portions of fixed size are obtained by cutting the gelatin rod in two with a simple cutting-machine, consisting of two hinged metal blocks. When the blocks are shut together, a cylindrical space is formed of the same dimensions as the gelatin rod. The apparatus also has a fork with fine metal wires stretched at equal distances from one another. The gelatin rod to be cut is placed in the groove in the lower block and held there in position by the upper block. To cut, the frame of the fork, which rotates on a hinged joint, is raised. The metal wires run in tracks cut in the metal block. (Cf. Fig. 1.)

To try out the suitable size to be cut, so as to get a piece that is not too large to chew and that at the same time provides sufficient material for analysis, a number of persons were made to chew bits of varying sizes. The experiences obtained here were used to determine a certain size, which was afterwards used

in all tests with adults. Smaller pieces were used for children from 7—13 years of age. As mentioned in the review of the literature different authors have used test portions of different sizes. Of course the results obtained to a certain extent will be influenced by these sizes. In this investigation, however, no analysis has been made of this influence. The method of testing the mastication raises a number of questions, and it has been found necessary to limit the scope of the investigation in regard to this and some other problems. Except for children the same size of the test portions has been used throughout and this difference between children and adults has to be remembered in the following.

The cutting-machine is so constructed as to divide up the gelatin rod into 6 equal pieces. Each portion for adults is 23 mm. in diameter, and 22 mm. long, which corresponds to a volume of 934 c. mm. (The equivalent piece for children has a volume of 623 c. mm.) It should be mentioned that this value refers to the volume before hardening and washing: during these further operations the portion swells to a somewhat larger volume.

The weight and volume of the finished portions may vary for several reasons. The volume increase set up in connection with hardening and washing may not always be the same. The cutter does not always give pieces of exactly the same size, which may be due to the fact that, if the wires have become less taut, they do not cut through the cylindrical gelatin rod absolutely at right angles. This source of error can be controlled to a certain extent, however; a slack wire can be tightened up, and crookedly cut pieces discarded. Finally, there is always the possibility that the barium sulphate may, on account of its weight, have sunk before the gelatin set. This tendency in the former substance is, however, comparatively small, on account of the high viscosity of the gelatin. A simple method has been used to check how far this may be so: slices of equal thickness were cut from both ends of a rod, after which they were X-rayed beside one another. The barium sulphate appeared in the picture as small dots. Some differences in density could be observed between the pictures, but only very slight ones.

In order to discover how far the finished portions all remain the same *weight* as one another, 25 made with 15 per cent gelatin and 25 with 15 per cent gelatin + 5 per cent barium sulphate were weighed in a precision balance.

The average weight of a hardened and washed portion of gelatin only is 10.9 g. with a variation coefficient of 1.2 per cent. The corresponding value for gelatin with barium sulphate is 11.4 g. with the same variation coefficient, i. e. 1.2 per cent. The portions used for children weighed 7.96 g., and had a variation coefficient of 0.44 per cent. The variability found can be considered of no importance; and the weight can be said to show good constancy.

A number of variations in weight are due to errors in weighing. A series of pieces were weighed twice to give an idea of how far this is so. These double weighings gave a variation coefficient of ± 0.18 per cent for gelatin only, and ± 0.28 per cent for gelatin with barium sulphate. The low figure shows that only a small part of the weight variation is due to errors in weighing, as might be expected, since precision scales are used. The main variation is plainly due to the fact that the pieces vary somewhat in size.

In order to get a further orientation, the *volume* of hardened and washed test portions was also determined. In 25 pieces of 15 per cent gelatin only, the average volume was found to be 10.4 c. cm. with a variation coefficient of 1.5 per cent. The corresponding values for 15 per cent gelatin with 5 per cent barium sulphate was 10.6 c. cm. and 3.5 per cent. For children, pieces with a volume of 7.4 c. cm. and a variation coefficient of 1.1 per cent were used. It was established by double determinations of the volume that the error of measurement for pieces with barium sulphate is 0.5 per cent, and for pieces without it, 0.9 per cent. Some part of the greater variation of the former compared with that of the latter can probably be ascribed to the uncertainty attached to the method for determining volume, but the difference cannot wholly be explained by the greater error of measurement. The investigation shows, however, that pieces of 15 per cent gelatin and those of 15 per cent gelatin + 5 per cent barium sulphate are both satisfactorily constant as regards volume and weight.

Before the pieces of gelatin are ready for use in mastication tests, they must be *hardened* in formalin, and the formaldehyde afterwards removed, so that they are not unpleasant to chew. The gelatin becomes harder in consistency and, most important of all, insoluble in water.

The formalin's content of formaldehyde varies between 36 and 38 per cent, so that the concentration of the diluted solution used for hardening varies between 4.45 per cent and 4.75 per cent. This

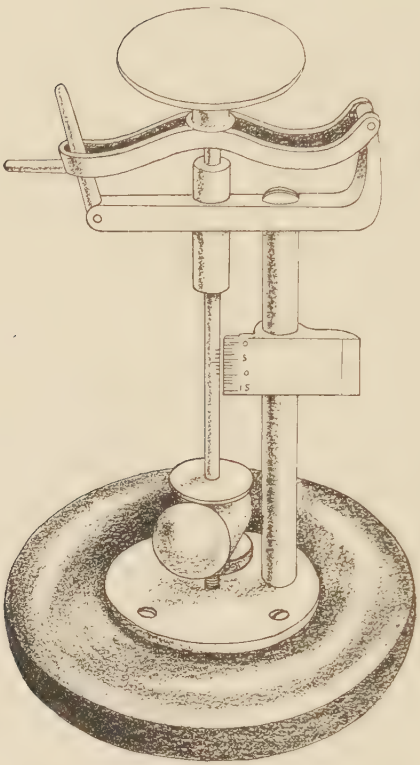

Fig. 2. Apparatus for measuring compressibility of gelatin.

variation constitutes a source of error, which is difficult to avoid in practice, so that it is of importance that the hardening procedure is in other respects as standardized as possible, to exclude further sources of error.

During hardening the test portions were kept in bottles with patent stoppers. The time taken was 24 hours, 50 test portions being hardened with 50 c. cm. of formalin, diluted with 350 c. cm. of water. After this it remains to treat the pieces so as to render them pleasant to chew; this is done by washing in running water. A rubber tube brings water from the tap into the bottom of the vessel where the pieces are. After 12 hours' rinsing, they have a completely indifferent taste.

As has already been said in the general discussion of gelatin as a test material, this substance has the advantage of varying as regards gelatin content and hardening. In the first place,

then, pieces with different content can be tested, and also pieces of different hardness. In the latter case, both the strength of the hardening solution and the time for its action can be varied.

The portions to be chewed are tested with a special apparatus which measures their compression under an increasing load. (Cf. Fig 2.) The apparatus has a plate which can be raised and lowered, and which has a groove in which the piece of gelatin lies firm. The gelatin is compressed by weights via a transforming device provided with a Vernier scale. The latter makes it possible to determine the compression at a certain load to $^1/_{10}$ of a millimetre. The resistance of the test portion to pressure can also be determined by the same apparatus. The set-up is the same, with the difference that the plate with which the portion is compressed is replaced by a blunt point 4 mm. in diameter. When the load reaches a sufficient height, the test portion splits into two halves.

Properties of the test material.

To get some idea of the properties of the test material, it has been investigated with reference to compressibility and resistance at different loads. It has been interesting to compare in these respects pieces of different gelatin content, some hardened in standardized wise, some hardened for longer or shorter periods with stronger or weaker solutions. It has also been of interest to investigate how far the material remains constant when kept.

A series of test portions has been tested with the apparatus described above, and the results are given in table 5. The numerical results here obtained give the compressibility expressed in millimetres at a load expressed in grammes.

It is now possible in the first place to make a comparison between the compressibility of pieces of different gelatin content hardened for the same time with the same hardening, and tested immediately after washing. It is found that the compressibility in tests with increasing loads from 200—1500 g. gets less with raised gelatin content. Thus, pieces of 10, 15 and 20 per cent gelatin with barium sulphate are, at a load of 1500 g., compressed about 3, 1.5 and 1 per cent of their diameter respectively. For these tests, the cylinder-shaped pieces are in a horizontal position. The variation is comparatively small, which means that the pieces are all alike. For 15 per cent gelatin with barium sulphate the value for the variation coefficient (= standard deviation expressed in per cent of the mean) is 3—5 per cent at different loads.

In a comparison between 10 and 15 per cent gelatin + barium sul-

TABLE 5.

Test pieces examined with regard to compression. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation. V = variation coefficient.

Load, g.	$M \pm \varepsilon(M)$	σ	V	Remarks
		10 % gelatin + 5 % $BaSO_4$		
200	1.734 ± 0.022	0.158	9.1	Test carried out immediately. Hardening during 24 hours in 50/350 formalin solution. 50 tests.
500	3.212 ± 0.030	0.213	6.6	
1000	4.984 ± 0.027	0.190	3.8	
1500	6.164 ± 0.031	0.220	3.6	
200	1.796 ± 0.013	0.089	5.0	Test carried out after 4 days. Hardening during 24 hours in 50/350 formalin solution. 50 tests.
500	3.380 ± 0.019	0.137	4.1	
1000	5.218 ± 0.021	0.151	2.9	
1500	6.424 ± 0.018	0.127	2.0	
		15 % gelatin		
200	0.520 ± 0.006	0.040	7.7	Test carried out immediately. Hardening during 24 hours in 50/350 formalin solution. 50 tests.
500	1.600 ± 0.010	0.072	4.5	
1000	2.746 ± 0.011	0.075	2.7	
1500	3.726 ± 0.013	0.091	2.4	
		15 % gelatin + 5 % $BaSO_4$		
200	0.508 ± 0.004	0.027	5.3	Test carried out immediately. Hardening during 24 hours in 50/350 formalin solution. 50 tests.
500	1.428 ± 0.010	0.072	5.1	
1000	2.502 ± 0.012	0.088	3.5	
1500	3.420 ± 0.013	0.092	2.7	
200	0.696 ± 0.007	0.053	7.6	Test carried out after 4 days. Hardening during 24 hours in 50/350 formalin solution. 50 tests.
500	1.610 ± 0.010	0.070	4.3	
1000	2.688 ± 0.011	0.079	2.9	
1500	3.630 ± 0.014	0.096	2.7	
200	1.200 ± 0.016	0.082	6.8	Test carried out immediately. Hardening during 12 hours in 50/350 formalin solution. 25 tests.
500	2.304 ± 0.019	0.093	4.1	
1000	3.788 ± 0.024	0.120	3.2	
1500	4.932 ± 0.019	0.095	1.9	
200	0.580 ± 0.012	0.058	10.0	Test carried out immediately. Hardening during 48 hours in 50/350 formalin solution. 25 tests.
500	1.432 ± 0.014	0.069	4.8	
1000	2.432 ± 0.019	0.095	3.9	
1500	3.264 ± 0.016	0.081	2.5	
200	1.096 ± 0.015	0.073	6.7	Test carried out immediately. Hardening during 24 hours in 25/350 formalin solution. 25 tests.
500	2.304 ± 0.021	0.106	4.6	
1000	3.888 ± 0.039	0.196	5.1	
1500	5.128 ± 0.043	0.215	4.2	

Table 5 (cont.)

Load, g.	$M \pm \varepsilon(M)$	σ	V	Remarks
200	0.312 ± 0.009	0.044	14.1	Test carried out immediately. Hardening during 24 hours in 100/350 formalin solution. 25 tests.
500	0.872 ± 0.012	0.061	7.0	
1000	1.628 ± 0.019	0.093	5.8	
1500	2.172 ± 0.019	0.094	4.3	
	20 % gelatin + 5 % $BaSO_4$			
200	0.300 ± 0	0	0	Test carried out immediately. Hardening during 24 hours in 50/350 formalin solution. 50 tests.
500	0.754 ± 0.011	0.079	12.2	
1000	1.560 ± 0.018	0.125	8.0	
1500	2.106 ± 0.016	0.110	5.2	
200	0.428 ± 0.006	0.045	10.5	Test carried out after 4 days. Hardening during 24 hours in 50/350 formalin solution. 50 tests.
500	0.924 ± 0.008	0.058	6.3	
1000	1.774 ± 0.012	0.082	4.6	
1500	2.356 ± 0.014	0.096	4.1	

phate we find the differences at different loads fairly small. They are nevertheless statistically significant, and increase from an average of 1.2 to 2.7 mm., constituting about 0.5 to 1 per cent of the diameter of the test piece. The differences between 15 and 20 per cent gelatin with barium sulphate, though statistically significant, are even less, being on an average 0.1—0.5 per cent of the diameter.

To investigate how far the addition of barium sulphate affects the test material, pieces of 15 per cent gelatin only have been tested and compared with 15 per cent gelatin + barium sulphate. The difference in compressibility at rising loads is very small, and when the load is 1500 g. the difference is only about 0.1 per cent of the piece's diameter.

Gelatin of different content was tested after having been kept 4 days, and a comparison with the results obtained after testing fresh pieces showed extremely small, though statistically significant, differences, indicating that the compressibility increases with keeping.

In hardening, a period of 24 hours with 50 parts of formalin and 350 parts of water has been used as standard method. A comparison shows that a hardening time of 12 hours gives softer pieces, and one of 48 hours harder pieces, than this. Differences at a load of 1500 g. between a hardening of 12 and of 24 hours are 10 times greater than the difference between one of 24 and of 48 hours. In the latter case, the difference is only 0.156 ± 0.021 mm.

Finally, 15 per cent gelatin with barium sulphate is tested after hardening, with 25 and 100 parts of formalin to 350 parts of water. Comparing the values with those obtained for standard-hardened gelatin of the same content, it is found that, at a load of 1500 g., the mild hardening gives

TABLE 6.

Test pieces, examined with regard to resistance by loading. $M \pm \varepsilon(M)$ = mean $\pm$ standard error. σ = standard deviation. V = variation coefficient.

Number of tests	Bursting point, kg. $M \pm \varepsilon(M)$	σ	V	Time of test after washing	Hardening, hours	Concentration of formalin
			10 % gelatin + 5 % $BaSO_4$			
25	0.932 ± 0.023	0.114	12.3	Immediately	24	50 350
25	1.040 ± 0.036	0.180	17.3	After 4 days	»	»
			15 % gelatin			
25	1.140 ± 0.018	0.091	8.0	Immediately	24	50/350
			15 % gelatin + 5 % $BaSO_4$			
25	1.196 ± 0.032	0.162	13.5	Immediately	12	50, 350
25	1.252 ± 0.016	0.082	6.6	»	24	»
25	1.276 ± 0.026	0.130	10.2	»	48	»
25	1.452 ± 0.013	0.065	4.5	After 4 days	24	»
25	1.140 ± 0.028	0.141	12.4	Immediately	»	25/350
25	1.776 ± 0.026	0.130	7.3	»	»	100, 350
			20 % gelatin + 5 % $BaSO_4$			
25	1.864 ± 0.011	0.057	3.1	Immediately	24	50, 350
25	1.828 ± 0.016	0.079	4.3	After 4 days	»	»

softer pieces with a difference of 1.708 ± 0.045 mm., and the stronger one gives harder pieces with a difference of 1.248 ± 0.023 mm. It is further found that mildly hardened 15 per cent gelatin agrees fairly well with 10 per cent gelatin hardened according to the standard method and also that strongly hardened 15 per cent gelatin shows about the same values as 20 per cent standard-hardened gelatin.

The test material has up to now been discussed with reference to compressibility. Table 6 gives the values for the load which causes the test piece to split into two halves.

A comparison between 10, 15 and 20 per cent gelatin with barium sulphate, hardened for an equally long time with equally strong solution (standard hardening) and tested immediately after washing, shows that the resistance increases with the gelatin content. Thus, twice the load, on an average 1.864 kg., is required to split a piece of 20 per cent gelatin content compared with one of 10 per cent. The resistance of 15 per cent gelatin is nearer that of 10 per cent gelatin; this is shown by the fact that the difference between 10 and 15 per cent gelatin is 0.320 ± 0.028 kg., and between 15—20 per cent gelatin it is 0.612 ± 0.023 kg.

The resistance in pieces of 15 per cent gelatin only was tested, and the values compared with corresponding values for 15 per cent gelatin + barium sulphate. It is found that the former has a somewhat lower resistance. The difference in the resistance for gelatin with barium sulphate is 0.112 ± 0.024 kg.

The resistance of the material when kept has also been tested. After 4 days, 15 per cent gelatin with barium sulphate shows an increased resistance, and the difference, compared with samples of fresh pieces, is 0.200 ± 0.021 kg.

The difference in resistance in hardening for 12, 24 and 48 hours shows only small differences, which are not statistically significant. On the other hand, the values for the differences show an increase of resistance in comparison with mildly hardened, standard-hardened and strongly hardened pieces.

Investigation of the test portions show that, as regards the compressibility and resistance of the material, small but statistically significant differences can be shown, above all as regards gelatin content and strength of formalin at hardening. On the other hand, the time for hardening (12—48 hours) and the keeping up to 4 days have played a smaller part. The test material would seem to possess suitable properties, since it remains fairly constant when kept, and since, above all, the values for the variation of test portions prepared in a standardized way, are small.

A further advantage is that, with the methods of testing the compressibility and resistance used here, it is possible to control the nature of the material. The mass-produced gelatin used can, of course, be suspected of variation, and the methods and values given provide a check in this direction. On account of the difficulties in procuring material, however, it has not been possible at this time to test gelatin from different factories.

With regard to the values obtained, it may finally be said that test portions with varying gelatin content showed moderate differences, but that 15 per cent gelatin rather seems to have the most constant character, i. e. to show the least variability in the portions as regards compressibility and resistance.

For the tests a material of 15 per cent gelatin and 5 per cent barium sulphate, hardened 24 hours in a solution of 50 g. of 36—38 per cent formalin and 350 g. of water, was used. The test portions were washed in water for 12 hours. The weight was 11.4 g. and the volume 10.6 c. cm. for grown-up persons. For children the weight was 7.9 g. and the volume 7.1 c. cm.

Chapter 5.

Division of the test portion into fractions by straining.

In the first experiments of the author to sort out the particles of the chewed portion into fractions, an apparatus was used that had a spray placed above the strainers. A device driven by an electrical motor moved the strainers horizontally backwards and forwards. But the apparatus was fragile, and troublesome to manage. The sluicing of the strainers proved uneven, as a number of particles blocked the holes, in spite of the shaking, and thus impeded the flow of water.

The apparatus.

The experiences gained from this apparatus were used in constructing another one, sturdier and more easier to manage, where the particles did not block the holes in the same way. This apparatus consists of 10 strainers, which can be pushed in from the side into a metal cylinder, through openings exactly adapted for this purpose, and can then be fixed in this position. Beside the metal cylinder there is a two-branched water-pipe and an inlet pipe from either branch is joined to each of the strainer pockets, to which water is thus brought direct. The branched pipe continues in two, 1.5 m. long main-pipes of glass, and in its lower part it has a water-distributing tap. Finally, the strainers have a side outlet in the form of a pipe the same height as the metal cylinder. In this way the rate of flow in all pipes to the strainers will be equal. (Cf. Figure 3.)

As the water is introduced from the side in each strainer, the whole system is washed through by a column in spiral rotation. The particles are sucked downwards towards the next strainer, and a number pass through, while others are stopped by the strainer, to be caught up in the flow of water again and make another attempt to get through. By repeating this sufficiently often, practically all the particles that can pass through, do so.

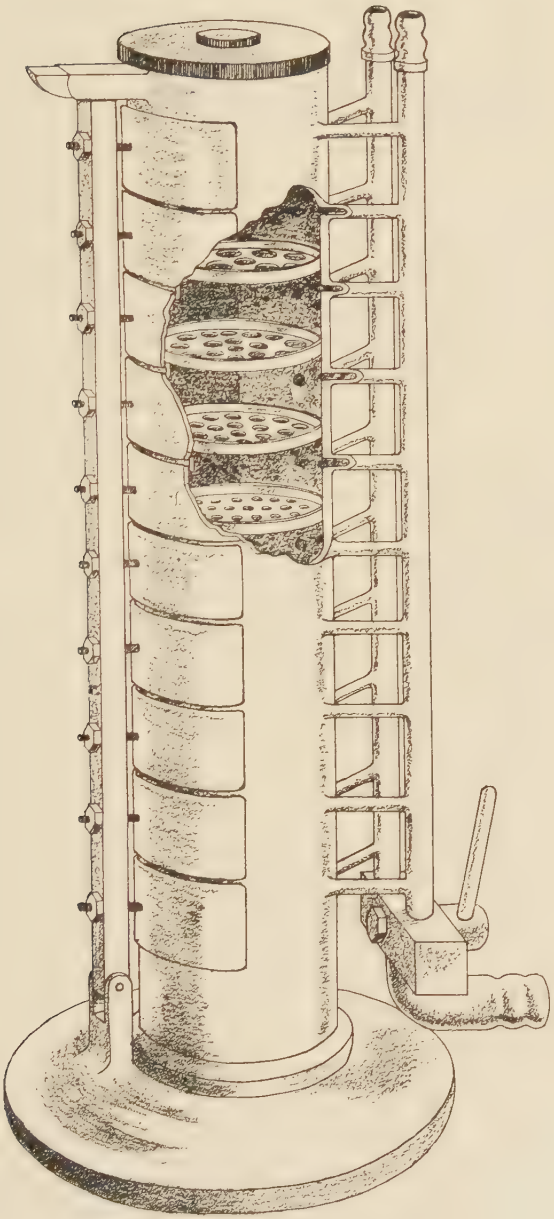

Fig. 3. Apparatus for straining.

It is possible, with the above-mentioned distributing-tap, to change the direction of the flow in the strainers, so that the column of water rotates now clockwise, now anti-clockwise. The tap can be set both in active position, when the water passes through either of the branches, and in neutral position, when the flow is stopped. In the latter position, the column of water sinks; the vortices are thereby increased and the particles are drawn downwards through the holes of the strainer. After a fixed number of seconds, the tap is turned back into the active position, the water spurts forth in the other shank of the pipe and the course of events is repeated, but with the column of water now rotating in the opposite direction.

The method of straining must be standardized as far as possible, in order to give comparable results. A stop-watch is used to ensure that a certain total time for straining is used, and also to check the time for the reversing of the jet of water. The water pressure must also be kept constant.

Under the circumstances which have been tested, the pressure of the water-system has proved to be fairly constant. When the tap in the supply pipe has been set to give the desired pressure, it does not as a rule need any further alteration, but this does not do away with the necessity of a certain control. Such control is easily carried out with the help of the water columns in the glass pipes.

These pipes are also a gauge of the precision with which the straining apparatus has been made, since the height of the water column in the parallel pipes will only be the same provided that the branched pipe and the inlet pipes on both the right and the left side have exactly the same dimensions. Thus, it needs no more than that a particle should be squeezed into one of the twenty inlets and there impede the passage of the water, for a distinct difference to arise in the level of the columns of water in the two branches.

To be used for mass investigations, the straining apparatus must, of course, be fairly easy to manage. The strainers are mounted in such a way as to be easy of access, and can quickly be taken out of the metal cylinder, emptied, and replaced. When removing and replacing the strainers, the tap is in the neutral position, so that the water pressure does not have to be regulated between each straining. It should be emphasized that the not inconsiderable lasting qualities of the apparatus have been

attained by its having only one movable part, namely the distributing tap.

In the apparatus, the diameter of the smallest hole is 1 mm., and increases by 1 mm. for each strainer in an arithmetical series up to 10 mm. for the largest holes. Yet another strainer, with holes $^1/_2$ mm. in diameter, has been used in a small number of strainings. It was introduced at the very bottom of the apparatus to control how much got through the 1 mm. strainer. The fraction collected on the $^1/_2$ mm. strainer was found to be extremely small. 75 test portions were strained. Several of these yielded an amount impossible to measure in the $^1/_2$ mm. strainer. On an average $0._{0968} \pm 0._{0091}$ c. cm. collected on the strainer, i. e. a volume of not quite $0._1$ c. mm. of very small particles.

In the determination of the size of the different fractions, the number of particles are counted in those from the less fine and the coarse strainers with holes 4—10 mm. in diameter. The determination of the three finest fractions, where the holes have a diameter of 1—3 mm. is made by measuring the volume after sedimentation in graduated glass tubes, since counting was found to take too much time. To get the volume, the contents of the strainer is emptied into a funnel filled with water, the particles rapidly sinking to the bottom of a graduated tube fixed under the funnel. Before reading off the volume, the particles should be shaken down until the volume remains constant. The device used, which is both simple and effective, consists of a spring which rests against an excenter-disc, driven by a motor. If the graduated tube is pressed against the plate in such a way as to be affected from the side by the latter's vibrations, it can be seen how the particles are shaken down and the volume quickly sinks to a constant value.

Pressure, rate of reversing and time.

In using the straining apparatus, it is possible, as has been said in Chapter 2, for certain factors to vary during straining, namely pressure, rate of reversing and the time taken. The question has been to find the combination of these three at which the apparatus gives the best results. A number of persons have chewed pieces of constant size and composition, after which double determinations were carried out in series of 30 tests, the same portion being strained twice. Table 7 shows that pressure,

TABLE 7.

Standard error of measurement for the mastication coefficient computed from differences between 2 strainings of a number of tests during different conditions. n = number of tests (each with 2 determinations). σ_i = standard error of measurement for a single straining. V = standard error in per cent of the corresponding mean.

Pressure	Time	Revision	n	σ_i	V
1. Highest	longest	slowest	30	0.017	0.9
5. »	long	slow	30	0.023	1.1
3. High	longest	»	30	0.032	1.9
6. »	»	slowest	30	0.044	1.9
4. Highest	long	»	30	0.037	2.0
8. High	short	slow	30	0.030	2.0
2. »	long	slowest	49	0.035	2.1
10. Low	»	slow	30	0.033	2.1
13. »	short	short	30	0.047	2.1
11. High	»	»	30	0.062	2.6
12. »	long	immediate	29	0.060	2.6
7. »	»	slow	30	0.045	2.8
15. »	»	short	30	0.083	3.6
14. Low	»	»	29	0.078	3.7
9. Highest	longest	slow	30	0.065	3.9
16. Low	long	immediate	26	0.086	4.2
17. »	short	slow	30	0.101	4.9

time for straining and reversing were tested in 17 combinations. The error in measurement for a single determination of the mastication coefficient has been calculated for each combination.

The different combinations are arranged in the table in a progressive series according to the percentual size of the standard error.

We shall first discuss the *pressure*. The figures show that low pressure is inferior to both high pressure and the greatest pressure, even though it may, in combination with a long period of time, give a standard error of only 2.1 per cent. In a comparison between high pressure and the greatest pressure, the latter is found to give a somewhat lower standard error in long or maximal periods of time. On the whole, then, the highest pressure is to be preferred.

Higher values for the error in measurement are found in immediate and short *reversing* than in slow and slowest reversing. Under otherwise similar conditions, the latter must be the best.

It now remains to test the *time* taken in straining. A short

time of 3 minutes gives a higher standard error than long or the longest time. If we compare these latter times, i. e. a straining time of 6 and 12 minutes, we find better values for 12 minutes.

As the table shows, the highest standard error is given by low pressure, short time, and slow or immediate reversing, it then amounting to between 4 and 5 per cent. As regards the standard error, it would naturally be wisest to chose the combination of highest pressure, slowest reversing and maximal time, which gives a standard error of only 0.9 per cent. However, from a practical point of view, another combination is preferable, namely high pressure, long time and slowest reversing. The highest pressure means that the water is to a relatively large extent squeezed out through leaks in the apparatus. The longest time makes the determination take nearly twice as long as it otherwise would. For these reasons, the author has chosen the second combination mentioned above. The standard error for this combination amounts to 2.1 ± 0.21 per cent, and is probably at a level to ensure satisfactory reliability of the method. To get a somewhat more exact idea of the standard error of the method, a larger number of determinations have been made for this combination than for others, namely 49. It should, incidentally, be pointed out that the differences between different combinations are to a certain extent conditioned by chance, due to the number of determinations not being very large.

The difference due to the error of measurement is of no very great importance when we consider that, in determining the mastication coefficient for an individual, we have to reckon with a not inconsiderable variation on account of the subject in question not always chewing in the same way, which causes differences between two tests. We have therefore considered ourselves justified in choosing a method which has advantages from the point of view of saving work, although its standard error is somewhat larger than the one characterizing a lengthy and more troublesome straining method.

As standard method, then we have chosen high pressure (100 cm.), longest reversing (12 seconds) and long straining time (48 seconds). The straining goes on in this way for 6 minutes. This method has a standard error of measurement in straining of about 2 per cent.

Chapter 6.

Testing of the test portion's calculated surface and volume.

In the theoretical discussion in Chapter 2 as to the way of calculating the surface and volume for the fractioned test portion, formulas were given on the assumption that the particles in the fractions correspond on an average to cubes and octahedrons respectively.

The calculations demand obtaining for the finer fractions — when the volume of these is known — the value of the number of particles in 1 c. cm. of sedimented volume. The particles in 20 c. cm. volume, measured out for each one of the finer fractions, were counted. The mean number of particles to 1 c. cm. in fractions where the strainer-holes were 1 mm. in diameter, was 545, in fractions with 2 mm. diameter 138, and in fractions with 3 mm. diameter 49.

From the above-mentioned formulas, it is possible to work out coefficients with which the volume of the different fractions can easily be calculated. The volume of the test portion is obtained by multiplying for fractions 1—3 their volume, and for fractions 4—10 the number of particles, by the respective coefficients. The values for the calculated coefficients are given in Table 8.

Coefficients for calculating the total surface of the test portion, drawn up on the same assumptions as in the calculation of its volume, are also given in Table 8.

Now, when the assumptions made render it possible to calculate the extent of the test portion's volume and surface, a simple expression for the degree of reduction can also be got by computing surface per volume unit. The value then obtained is called here the *mastication coefficient* for the reduction of the portion. The calculated volume and surface do not necessarily correspond to the actual ones, but then the calculated values should differ in the same direction from the actual ones. If, by

TABLE 8.

Coefficients for calculation of volume and surface. It is assumed that the particles in fractions 10—4 correspond to cubes and the particles in fractions 3—1 to octahedrons.

Number of fraction									
1	2	3	4	5	6	7	8	9	10
Coefficients for calculation of volume									
303.97	362.87	348.75	32.22	58.83	97.11	149.18	217.16	303.17	409.34
Coefficients for calculation of surface									
2139.33	1506.75	1035.33	60.75	90.75	126.75	168.75	216.75	270.75	330.75

assuming that the particles have the form of octahedrons, too low a value is obtained for the volume, the values for the surface ought also to be too low, and in the same way, if a calculation assuming the form of cubes gives too high a value for the volume, the value for the surface should also be somewhat too high. In calculating the mastication coefficient therefore, it is more correct to relate the calculated surface to the calculated volume than to relate it to the known volume. This procedure has consequently been followed throughout.

Table 9 gives the average values for calculated surface and volume for grown-up men and women whose sets of teeth are extremely good, good, bad, and extremely bad.[3] The test subjects chewed standardized portions until they felt ready to swallow.

The calculations show that if we assume the particles to correspond on an average to cubes with a side diagonal half-way between the diameter of strainer-holes letting the particles through and that of those that do not, the value obtained for the calculated volume is too high compared with that of the actual volume; the values agree rather better, however, when the fractions are large on the coarse strainers and small on the finer ones, as is the case with extremely poor sets of teeth. In the opposite case — with good sets of teeth — with large fractions on the finer strainers, larger values are obtained for the calculated volume compared with the actual one. The deviations can be 35—40 per cent. It therefore seems as if the assumption

[3] A closer definition of what is implied here by extremely good, good etc. sets of teeth will be given further on in this paper.

TABLE 9.

Mastication coefficient calcutated from figures for surface and volume determined on the basis of means of the fractions for men with extremely good sets of teeth (63 persons), good sets of teeth (60 persons), bad sets of teeth (51 persons) and extremely bad sets of teeth (55 persons), and on the basis of means of the fractions for women with extremely good sets of teeth (61 persons), good sets of teeth (76 persons), bad sets of teeth (50 persons) and extremely bad sets of teeth (50 persons). M. C. = mastication coefficient, sq. cm./c. cm.

Set of teeth	Assumed shape of particles at calculation								
	Cube 1—10			Octahedron 1 -3, cube 4 -10			Octahedron 1 - 10		
	Surface, sq. cm.	Volume, c. cm.	M. C.	Surface, sq. cm.	Volume, c. cm.	M. C.	Surface, sq. cm.	Volume, c. cm.	M. C.
Men									
Group I, extremely good	363.92	14.665	24.8	252.44	10.553	23.9	210.09	6.913	30.4
» II, good	276.85	14.086	19.7	214.49	11.647	18.4	159.82	6.640	24.1
» II, bad	229.44	13.185	17.4	188.36	11.556	16.3	132.45	6.215	21.3
» IV, extremely bad	218.44	12.945	16.9	180.25	11.457	15.7	126.11	6.102	20.7
Women									
Group I, extremely good	347.16	13.934	24.9	241.67	10.094	23.9	200.42	6.569	30.5
» II, good	284.87	13.329	21.4	211.21	10.552	20.0	164.45	6.283	26.2
» III, bad	244.75	12.879	19.0	191.36	10.826	17.7	141.30	6.071	23.3
» IV, extremely bad	228.30	12.566	18.2	183.41	10.832	16.9	131.30	5.924	22.2

that the particles are, on an average, cube-shaped, only applies to the not so fine and the coarse fractions with fairly large particles.

If, on the other hand, calculations are carried out on the assumption that the particles correspond on the whole to octahedrons, where, if the base diagonal is the same size as the cube's side diagonal, the volume of the former will be less than that of the latter, the values obtained for the test portion's calculated volume are throughout smaller than the actual volume. The deviations are 30—40 per cent. They seem to be somehwat less when the fractions on the fine strainers are large, i. e. with good sets of teeth, compared with bad sets, when the fractions in the fine strainers are small. On closer inspection of the shape of the particles in a test portion, they seem, further, to be preponder-

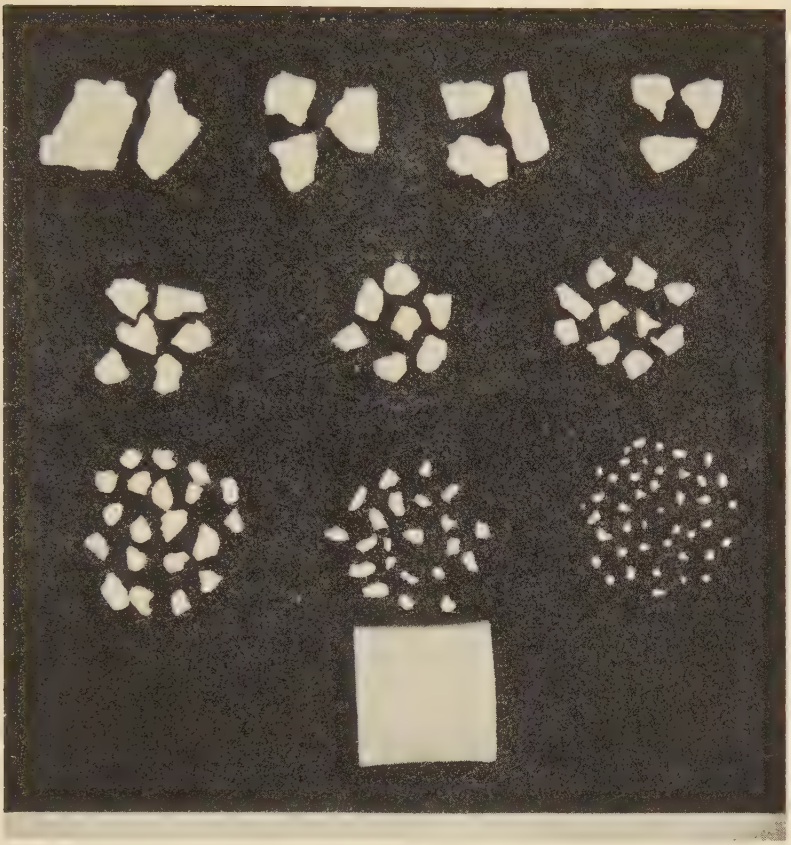

Fig. 4. Samples in nearly natural size of the different fractions and a test portion.

atingly pointedly oval in form in the finer fractions, and more rounded in the less fine and coarse ones. (Cf. Figure 4.) Actually, the calculated and actual volumes are found to tally very well if the calculations are made with octahedrons for the fractions for strainers 1—3, and with cubes for those 4—10. With a view to getting an idea of the deviations between the real values and the computed figures the differences between these have been calculated for 229 men and 237 women. It has been found that for women there is no appreciable mean deviation. The mean of the differences is 0.86 ± 0.65 per cent. For men the corresponding figure is 6.6 ± 0.76 per cent. The computed volume is somewhat greater

than the real. Of special interest is the fact that the standard deviation for men is 11.6 per cent and for women 10 per cent. This signifies that sometimes quite large deviations between the computed and the real values may arise.

Table 9 also gives the values for the mastication coefficient calculated from the average surface per volume unit. It may be of interest to compare the values obtained in calculations made on different assumptions. The highest values for the mastication coefficient are found in calculations assuming that the particles correspond throughout to octahedrons, and the lowest values in those where cubes and octahedrons have been combined. The table shows, further, that the coefficient gets less as the sets of teeth get worse. For a closer comparison of the coefficients for varying sets of teeth, however, readers are referred to the latter part of this work.

Control by weighing.

It is now possible to get a further control for the calculations of the test portion's volume. The fractions are weighed, and from the weights is calculated — when the specific gravity is known — the volume for each fraction. Still using the same test portion, a calculation, based on the number of particles and the measured sedimented volume, is made of the volume of the different fractions.

An investigation of this kind has been carried out on 10 test portions. Table 10 gives, for purposes of comparison, figures which have been calculated both from the weight of the portion and also from the number of particles and the sedimented volume.

The figures in the table show us that there is good accordance between volume calculated from the weight of the test portion, and volume calculated on the assumption that the particles in fractions 1—3 correspond to octahedrons, those in fractions 4—10 to cubes. The average difference is 0.30 ± 0.10 c. cm. or 3.04 ± 1.04 per cent. A corresponding comparison on the assumption that the particles in all the fractions are in the form of cubes shows throughout higher values, with an average difference of 2.40 ± 0.20 c. cm. or 24.0 ± 2.0 per cent, and on the assumption that they have the form of octahedrons, the values are lower throughout, with an average difference of 4.14 ± 0.15 c. cm. or 41.5 ± 1.5 per cent.

TABLE 10.

Volume calculated from weight and number of particles of fractions of 10 tests.

Test	Weight, g.	Volume calculated from weight, c. cm.	Volume calculated from number of particles		
			Cube 1—10	Octahedron 1—3, cube 4—10	Octahedron 1—10
I	11.37	10.57	12.91	10.73	6.09
II	10.83	10 07	12.80	10.40	6.03
III	9.51	8.84	12.02	9.13	5.67
IV	10.73	9.98	12 01	9.90	5.66
V	12.17	11.32	13.67	12.00	6.45
VI	10.30	9.58	11.76	10.21	5.54
VII	10 07	9.36	11.50	9.90	5.42
VIII	10.31	9.59	10.68	9.24	5.04
IX	10.73	9.98	13.24	10.53	6.24
X	11.11	10.33	12.98	10.61	6.12

By weighing the particle mass and calculating the volume for the last three fractions, we can get an idea of how much of the measured volume consists of water. A calculation has been carried out on 10 test portions; the average amount of water in 1 c. cm. for fractions remaining in the strainer with holes of 1 mm. in diameter is found to be 50.6 per cent, for fractions with strainer-holes 2 mm. in diameter 50.7 per cent and for fractions with strainer-holes 3 mm. in diameter 50.3 per cent. A calculation of the amount of water made from the measured, sedimented volume on the assumption that the particles are in the form of cubes, gives 35 per cent, 23 per cent and 26 per cent respectively. The same calculation assuming the particles to correspond to octahedrons gives 69 per cent, 64 per cent and 65 per cent respectively. It is probably true that the volume values, calculated from the weight of the fractions are somewhat higher than the true values, since there is no doubt a certain amount of water in the weight obtained. (The particles were dried with the help of filter paper, and this drying is sure not to be completely effective.) For this reason the percentage values calculated from the weight are very likely too low. The real values for the average content of water should therefore lie quite near those obtained from the sedimented volumes on the assumption that the particles correspond, on the whole, to octahedrons.

Colorimetrical control.

We have now shown that the volume of the test portion to be chewed can be determined direct by weighing, and that the values obtained agree with the values calculated from the number of particles and the measured, sedimented volume after fractionation. We have further shown that the calculated volume agrees with the actual one of the test portion. The portion's surface is now calculated from the same fractions as its volume was, and we should therefore be able to expect the calculated surface to agree fairly well with the actual one. Nevertheless, it would be a good thing if the surface could also be determined direct, without previous fractionation, in order to check the calculated values in the same way. It should be possible to gauge the total surface of the portion by treating it with a suitable chemical, which can be absorbed, and which has the further property of being removable again and able to undergo a quantitative analysis. At the suggestion of Professor TORSTEN TEORELL, the author has tried out a method which consists in staining the test portion with a water-soluble, colloidal dye and, after washing out of the latter, the photometric determination of the intensity of colour in the solvent.

In the first experiments, a water-soluble dye, Nachtblau, was tested. The colour of the fluid was read off on a Pulfrich (Zeiss) photometer of usual construction. After trying out the dye concentration most suited for reading off on the photometric scale used, a concentration of 1 promille was chosen as standard colouring-fluid. A number of thin slices of formalin-hardened gelatin with known surface-volume (10.92 sq. cm.) were coloured with equal quantities of the fluid. The experiments showed that the values read off gave a higher colour intensity in the fluid after the colouring process than before it. Further, the photometer gave a larger reading after colouring a bigger gelatin surface than after colouring a small one. A microscopic investigation of the colouring-fluid after use revealed that a precipitation of colouring grains takes place during use, and this explains the above-mentioned rise of the values read off from the apparatus. Formalin-hardened gelatin has an acid reaction, and as this might possibly produce the precipitation, the experiment was made of adding weak acid to the colouring-fluid. Microscopic investigation showed precipitation. Weak alkali was now added to the fluid instead

of acid. The precipitation of grains became even more marked. Under such circumstances, it is plain that Nachtblau is unsuitable as a colouring matter in a colorimetrical test such as is intended here; precipitation can be obviated only when the reaction is practically neutral.

In consideration of the formalin-hardened gelatin's acid reaction, a watersoluble colloidal dye, Congo-red, was tried; it does not react with precipitation of grains when small amounts of acid are added. A concentration of 1 promille was again chosen as standard colouring-fluid, and 96 per cent alcohol was taken as solvent.

When trying out the colorimetrical method, the first concern was to determine suitable times for colouring and decolouration. In a concentration of 1 promille, there is such superfluity of colour that the dying of a gelatin surface twice the size of that of an average test portion hardly makes any difference at all to the intensity of the colouring-fluid. A decrease was with difficulty read off after dying 24 gelatin slices with a total area of 262 sq. cm.

To reach a standardized method, the first thing to do is to try out the time the colour takes for maximal absorption into the surface of the gelatin, and, further, the time taken for decolouration in alcohol. Gelatin slices cut from test samples with an area of 10.92 sq. cm. were used for this.

It was now found that the same value was obtained after 10 minutes as if the pieces of gelatin had been left in the colouring-fluid for 3 hours. No investigation was made into how quickly the dye is otherwise absorbed. In subsequent tests, 10 minutes colouring was used.

After this, the time for decolouration was tested. The result was not the same after 20 minutes as after 10, but after 20 minutes the colour content in the decolouring fluid remained constant. In subsequent tests, therefore, a time of 20 minutes was used.

Finally the values for the colour intensity corresponding to surfaces of different area were determined, with a view to getting an idea of which photometer readings correspond to known surfaces in the proximity of the surface area of a test portion. For this reason, the readings corresponding to 12, 18 and 24 slices were determined repeatedly. As the figures in Table 11 show, the readings in this region lie practically on a straight line, and with the help of these values, it is possible, by means of inter-

TABLE 11.

Photometer figures, corresponding to different number of gelatin disks with a surface of 10.92 sq. cm.

Number of disks	Surface, sq. mm.	Photometer figures
6	6552	330
12	13104	470
18	19656	530
24	26208	570

polation, to calculate the surface corresponding to a certain reading on the photometer.

Aided by the figures obtained in this way, 16 further test portions were investigated; in the first place in that surface and volume were calculated on the basis of the values obtained when the respective portions were strained, in the second place in that the portions were coloured and the surface determined with a photometer. The values obtained are shown in Table 12.

It is found that the separate values admittedly show deviations, but that, on the whole, they agree pretty well.

TABLE 12.

Surface and mastication coefficients (M. C.), calculated on the basis of straining and on the basis of colour determination of 16 tests.

Test	Calculated volume, c. cm.	Calculated surface, sq. cm.	M. C.	Colourdetermined surface, sq. cm.	M. C.
I	9.477	140.13	14.8	160.52	15.1
II	7.911	220.04	27.8	212.94	20.1
III	9.021	134.49	14.9	150.70	14.2
IV	8.554	231.48	27.1	262.08	24.7
V	9.727	121.08	12.4	147.42	13.9
VI	8.407	247.55	29.4	262.08	24.7
VII	9.115	124.94	13.7	119.34	11.3
VIII	7.933	229.21	28.9	172.54	16.3
IX	9.219	118.98	12.9	117.00	11.0
X	8.883	244.67	27.5	180.18	17.0
XI	10.216	134.16	13.1	118.40	11.2
XII	8.261	216.53	26.2	180.18	17.0
XIII	9.829	122.96	12.5	124.02	11.7
XIV	9.046	244.47	27.0	193.28	18.2
XV	10.289	107.07	10.4	124.49	11.7
XVI	9.263	256.13	27.7	191.10	18.0

Geometrically calculated volume:	$M = 9.07 \pm 0.18$ c. cm.,
	$\sigma = 0.73 \pm 0.13$ c. cm.
Geometrically calculated surface:	$M = 180.9 \pm 14.6$ sq. cm.,
	$\sigma = 58.5 \pm 10.3$ c. cm.
Geometrically calculated mastication coefficient:	$M = 20.7 \pm 2.0$ sq. cm./c. cm.,
	$\sigma = 8.0 \pm 1.1$ sq. cm./c. cm.
Real volume:	10.6 c. cm.
Colour-determined surface:	$M = 169.8 \pm 11.8$ sq. cm.,
	$\sigma = 47.1 \pm 8.3$ c. cm.
Colour-determined mastication coefficient:	$M = 16.0 \pm 1.1$ sq. cm./c. cm.,
	$\sigma = 4.4 \pm 0.78$ sq. cm./c. cm.

The difference between the geometrically determined surface and the colour-determined surface is 11.1 ± 18.8, therefore lying within the limits of the standard error. The difference for the mastication coefficients is 4.7 ± 2.3, so they agree satisfactorily. Nor are there any statistically significant differences as regards the variability. Now, the number of determinations is not great, and perhaps, in a larger material, it might be possible to show systematic deviations between the two methods of determining surface and mastication coefficient. All that is of interest to establish in this connection is, that any such deviation should be moderate in size, and that results are reached in the colour-determination of the surface that may be used to verify the values obtained by a geometrical calculation.

Chapter 7.

Summary: The standard method and its errors.

The standard method chosen as a result of the investigations made can be briefly characterized as follows.

For material, pieces of 15 per cent gelatin and 5 per cent barium sulphate have been used. The pieces were hardened for 24 hours in a solution consisting of 350 g. of water and 50 g. of 36—38 per cent formalin solution. The pieces had a volume of 10.6 c. cm. and a weight of 11.4 g. The material fulfils certain demands as regards compressibility and resistance. By this means it can be checked whether the material has the character required in the standard tests.

In the test, the subject is asked to chew the piece either until he considers it ready to swallow, or else for a certain number of times. When carrying out the test, different procedures have been used as regards this; they will be discussed later. The test subject then spits out the piece into a glass, and it is divided up into fractions by means of water-straining in a special apparatus. For this are used a pressure of 100 cm. of water, a reversing of the flow with an interval of 12 seconds and a straining time of 48 seconds during 6 minutes. After this, the particles in the 7 coarser fractions are counted, and the volume of those in the 3 finest fractions, where the strainer holes were 3, 2 and 1 mm. in diameter, is determined in graduated glass tubes by sedimentation in water. In estimating the degree of reduction, special formulas have been used to calculate the portion's total volume, its total surface, and, finally, the mastication coefficient giving surface per volume unit. Already in the preliminary experiments, distinct differences could be established between the results when the subjects had gone on chewing as long as they wished and when they had only chewed 40 times, as also differences in chewing by people with good and bad sets of teeth

respectively. The more effective the chewing, the greater the portion's surface per volume unit. These problems will be discussed in Part II.

The standard error of the method has been calculated with the help of double determinations (cf. Table 7). It has been found that the error of measurement attached to a single determination of a mastication coefficient, and which is conditioned by errors in the actual straining, is about 2.1 per cent (cf. Table 7). The standard error obtained for a determination of a mastication coefficient when a given person chews repeatedly, is much greater, due to the fact that a subject does not chew in exactly the same way when he performs a test more than once. This error seems to be greater for men, 10.3 per cent, than for women, 8.6 per cent. (Cf. Tables 49 and 60.) It is, of course, not possible to escape this variability by improving the methods. If the mastication coefficient is determined for someone with a single test, there are, all the same, not inconsiderable factors of uncertainty to reckon with, and if a more reliable orientation of a person's mastication is wanted, he must be subjected to a series of tests.

Considering that the error in the determination of the mastication coefficient by straining is comparatively small, this method is, as a matter of fact, fairly exact. Further, it does not take much time, so that it is well suited for mass investigations. It also seems reasonable to assume that the method could be used for practical tests of judging the masticatory powers in separate patients; though in individual cases like that, a series of tests should be made, in order to reach reliable mean values. If, for instance, 10 tests are made on an individual, the standard error of the mean of the tests should be about 3 per cent.

Part II.

Investigation of mastication with complete and with more or less defective sets of teeth in men and women of different ages.

Chapter 8.

Introduction.

In the previous section we have stressed the desirability of getting an idea of the mastication effect and its relation to the number of the teeth. The method worked out and described here is sufficiently exact and, at the same time, does not take so long as to render it impossible to investigate a material large enough to provide a survey of how effectively persons chew in an average population.

When selecting material for investigation, certain viewpoints ought to be taken into consideration. We must reckon with the possibility of there being differences in the mastication effect both between men and women with similar sets of teeth, and also for different ages. From these points of view, it is advisable to investigate the same number of men as women, as far as this is possible, and also to keep material concerning children, adults and old people all separate from one another in the experiments. Then, a most important consideration, people with more or less complete sets of teeth may be expected to chew with different effectivity. The investigation material should therefore be grouped with regard to the quality of the sets of teeth. It is of special interest, finally, to investigate how people with complete dentures chew, and, in so doing, also compare the masticatory powers here with those in people with their own teeth.

Using as basis the investigation material comprising the different groups indicated here, it should be possible to reach a fairly well differentiated picture of some of the physiological features involved, and get something to go on for an estimation of the masticatory powers under different conditions, specially in a defective set of teeth and an artifical denture; all this may well yield information which is also of some value for practical dentistry.

Chapter 9.

Material.

The material for investigation has been mainly collected in schools, regiments, factories and almshouses. Guided by the viewpoints given above, the subjects were divided into the following groups.

I. *Children.* The group consisted of schoolchildren, half with their milk teeth and half with permanent sets. There were 50 boys and 50 girls of 7 years of age, and 50 girls and 50 boys of 13 years of age.

II. *Adults with their own teeth.* The investigated persons were conscripts and older mobilized classes, and women of corresponding ages — i. e. 20 — 45 years. 62 persons over 35, but not over 45, were included in this group, but only such whose sets of teeth were not considered to show age changes. There were 229 men and 237 women.

III. *Older persons with their own teeth.* The investigated persons were from 50—75 years of age. There were 101 men and 50 women. The men were examined at a workhouse in Stockholm; neither in factories nor almshouses was it possible to find more than a very small number of women with their own teeth who were suitable for investigation. The material consisted mainly of persons who volunteered for investigation in my clinic.

IV. *Adult and older persons with full dentures.* The investigated persons were about 40—80 years of age, and consisted of 50 men and 50 women.

When judging whether a set of teeth is 'good' or 'bad' from a functional point of view, it is necessary in some way to evaluate the teeth that are antagonists and that can function completely.

A number of authors have discussed evaluation questions of this kind.

One of the first who attempted to submit figures for the mastication value of the teeth was FEILER (1916). He reckoned a functioning molar as one unit, and a bicuspid as half a unit. He ascribed no mastication value to incisors and canines. Different scales of values have later been drawn up by a number of authors. MICHAELIS (1920) reviews the literature in this field without, however, advancing any suggestion of his own. HENTZE (1917) uses, for example, the following scale: incisors and canines are each one mastication unit; the first bicuspid is 2 units; the second bicuspid 3 units; the first and second molars each 6 units. The third molar is not thought to have any value. ROHRER (1919) uses the following scale: incisors and canines each 0.25 mastication units; bicuspids and the first and second molars each one unit; the third molar 0.5 of a unit.

These scales are only given here as examples. They are *a priori* estimates and are not based on empirical investigations. Nor do they take into consideration that teeth do not consistently correspond to one another: a grinder in the lower jaw has for instance occlusion with parts of several teeth in the upper jaw.

In this paper the author has first of all registered the number of teeth. This number does not, of course, give any definite conception of the effectivity of the set; this can be estimated with more certainty by the number of occlusion contacts between the two rows. It is all the same impossible to determine the contacts exactly without first making models of jaws and teeth and mounting these in an articulator. In a mass investigation, it is necessary to classify the sets of teeth quickly, and at the same time with reasonable certainty. In doing this, the author used an *a priori* enumeration of points, according to which the surfaces of the teeth are imagined as divided into sections. In an inspection of the rows of teeth in central occlusion, we can tell which sections in the upper and lower jaws correspond to one another. A contact between two sections is given 1 point. Figure 5 shows how the calculation of points for an ideal set of teeth is carried out.

It is seen from the schematic figure that molars, with the exception of the wisdom teeth in the upper jaw, are divided into three sections; further, that pre-molars and canines are divided into two sections. The other teeth are not divided.

A classification of the set of teeth from a *functional* point of view can now be made by counting the number of points for

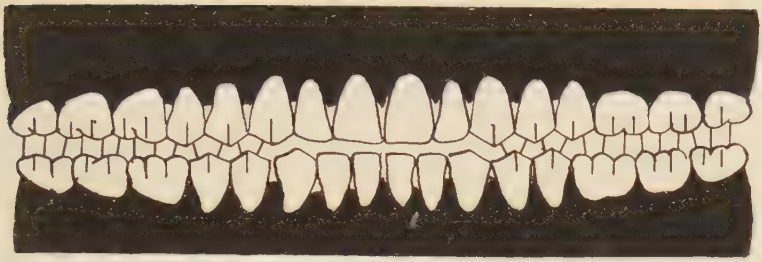

Fig. 5. Points of contact for the grinders in a normal set of teeth.

Fig. 6. A defective set of teeth with regard to calculation of points of contact. Compare Fig. 5 and the text.

grinders, canines and incisors. The canines assume an intermediate position inasmuch as the distal section of these teeth is reckoned as a grinder and the mesial section as an incisor. The value of the points should give a fairly good picture of the variation, set up not only by losses in teeth but also by anomalies in occlusion and position, in the number of contacts. A complete set of teeth has 32 contacts, 26 to the grinders and 6 to the incisors.

It has also been of interest to determine with a point scale the extent to which the sets of teeth investigated were defective as regards missing teeth and loss of substance in those that were left — in other words, to classify the sets from an *anatomical* point of view, independent of how far contacts may be present for such teeth as remained. Intact teeth — i. e. teeth with no loss of substance — were given 1 point. Defective teeth had 0.75, 0.50 and 0.25 points, according to the extent of the substance lost. 0 signified root stumps and missing teeth.

Figure 6 shows how the calculation of points in a defective set of teeth has been made. The defective set of teeth in the figure

shows 14.50 points for molars and pre-molars (grinding teeth), and 12 points for canines and incisors (cutting teeth). The total for the whole set is 26.50 points.

With the help of a calculation of points of contact the sets can be classified as extremely good, good, bad and extremely bad. As the investigation is intended to work out the effect of mastication, the sets have been grouped with regard to the number of contacts for the grinders. The limits used have been chosen to lie between 26—16 points for extremely good sets, 15—11 for good sets, 10—8 for bad sets and 7—0 for extremely bad sets.

It has already been said that the calculation used is entirely arbitrary. A more rational procedure is to determine the area of the *occlusion surface*. To this end, each test subject with his own teeth was made to bite into a wax plate, 2 mm. thick, care being taken to see that this was done in central occlusion. The wax impression is transferred onto a film, and its surface determined with a planimeter. The value obtained gives the surface in sq. mm. Completely misleading results can be obtained in isolated cases, on account of incorrect biting when the test was made. To get comparable values, the persons investigated were instructed to bite on the wax with the teeth in central occlusion. If this is done with the lower jaw in protrusive or in lateral occlusion, the surface of the wax impression will be smaller. If, on the other hand, the lower jaw then slips into central occlusion, the impression surface will be larger than it is after a direct bite in central occlusion.

The wax impression had a thin, transparent, inner zone with sharp borders, and an outer one which was thicker and had rather indistinct borders. When copying the impression, the outermost contours were followed, in order to get a maximal value for its surface.

Double tests have been made to get an idea of the method's sources of error, and its standard error has been calculated from the differences. The error of measurement is due partly to the biting in two separate tests not being exactly alike, partly, too, to the fact that the transference of the wax impression to a film, and the measuring of one and the same specimen, do not give exactly the same values in two copyings and measurings. The total error, which consequently consists of errors in biting and in technique, has been determined on 25 persons and amounts

TABLE 13.

Distribution of the material with regard to age and sex.

Age, years	Men	Women	Old men	Old Women	Full prosthesis		Total		Both sexes
					Men	Women	Men	Women	
7	50	50					50	50	100
13	50	50					50	50	100
16—19	13	20					13	20	33
20—24	146	65					146	65	211
25—29	25	58					25	58	83
30—34	26	48				2	26	50	76
35—39	9	33			1		10	33	43
40—44	8	12			1		9	12	21
45—49	1	1	1	5	3	1	5	7	12
50—54	1		15	19	7	2	23	21	44
55—59			19	13	10	2	29	15	44
60—64			35	6	11	4	46	10	56
65—69			20	3	12	6	32	9	41
70—74			10	2	4	9	14	11	25
75—83			1	2	1	24	2	26	28
Total	329	337	101	50	50	50	480	437	917

to 2.7 per cent in a single determination. For a further idea of the technical error, 25 wax impressions have been copied twice and their surfaces determined twice, the standard errors being calculated from the differences. The error which attaches to one diagram and measuring amounts to 1.7 per cent. It is thus found that the total standard error of 2.7 per cent is composed of a »biting» error of 1.7 per cent and a »technical» error of 1.7 per cent. It may be said that the actual measuring can be carried out fairly exactly. The most important source of the technical error lies in the copying, which was to be expected. Of course it is to be expected that systematic errors also play a part. Howewer, it is not necessary to discuss them in this connection, as all the determinations have been made in the same way by one and the same person.

In the following pages, it has been investigated how far the calculation of points according to the author's scale has given values that run parallel with those obtained in the determination of surface. The determination of surface has, furthermore, been used throughout the treatment for an analysis of the masticatory effectivity, as this latter has been considered more reli-

able under all circumstances. As the investigation shows, however, a satisfactory measurement of the occlusal surface can be got from the point scale, too, so that this can be used if time does not allow the more laborious determination of the occlusion surface.

Table 13 collocates the investigation material grouped with regard to age and sex. The table shows the total material to comprise 917 persons. The intention has been to get about 50 individuals in each group exemplifying different sets of teeth, and this was possible to do for adult men and women. As far as children were concerned, the author has been content with about 50 for each class of age, if boys and girls are put together. It has, however, not been possible to get so large a material for the group with extremely bad sets of teeth. When it comes to older men and older women, the author has had to put up with a smaller material, as also in question of persons with full dentures. The difficulties of getting further material have been great, and the extent of that in hand has been considered sufficient, with the background of the larger adult groups, to allow of a comparison. As regards individuals with full dentures, no more will be said here than that they have been classified in three groups: those with extremely good, good and bad sets of teeth respectively, and that this grouping has subjective judgments at the back of it. We shall be discussing these questions in more detail later in this paper.

Chapter 10.

The taking of specimens.

Each investigated person was made to chew five test portions one after the other. Between each portion, he was made to rinse out his mouth three times, and the water with which this was done was kept. In cases with full dentures, these were also taken out and sluiced with water, which was afterwards saved. The number of chews each time were counted. This was not as a rule a difficult process, except in isolated cases when the test subject chewed with small and rapid movements of the jaws. The chewing movements were counted in 130 tests by two people simultaneously. The differences in the standard errors showed a difference of -1.26 ± 0.44, bordering on statistical significance. The difference is so small as to have no importance, and would seem to show that such counts can be made with satisfactory exactitude.

The *first* test portion was chewed just as the test subject liked: he was not influenced in any way. The idea of this was to provide some practice for subsequent tests. The portion was all the same saved and analysed, as it was, of course, of interest to determine the results and number of the chews.

The *second* and *third* portions were chewed on the express instructions to chew until the mass felt ready to be swallowed in the same way as if it were food. It should be mentioned that there is a difference in the chewing here, compared with that of food: in the latter case, one swallows while chewing, so that the whole of the mouthful does not go down at once. To get a control, a third mastication test was made, consisting of a repetition of the second; this time, too, the subject was told to chew until he felt ready to swallow.

Over and above this free mastication, where the test subjects themselves determined the number of times they chewed, two tests were made where the test portion was *chewed 20 and 40 times*. By fixing the number of chews, it becomes possible to com-

pare the results without risking differences conditioned by variations in this respect.

Inspecting the teeth of the patient, entering the details and taking of the specimen require a total time of 20—30 minutes. The analysis of five specimens takes, on an average, an hour. Generally, a larger number of specimens was taken at one time, so that it was sometimes a day or so before they were analysed. For this reason it was considered advisable to conserve them by adding a few drops of formalin to each.

Chapter 11.

Number of teeth and occlusion contacts in the investigated population.

This is an investigation into masticatory effectivity, and on this account the main stress when registering the sets of teeth has been laid on the determination of the number of occlusion contacts and the area of the contact surfaces.

The number of teeth has also been registered, however, and as certain groups of the persons investigated are not selected, so that the material can be considered fairly representative, we may be motivated in giving data as to the number of teeth in it. As has been said before, the teeth were evaluated according to a point scale from 0.25, 0.50, 0.75 to 1.0. The value 1.0 implies that the tooth has a complete occlusal or incisal surface independent of whether it is intact or treated with filling or prosthesis. The other values, which apply to teeth with defective occlusal or incisal surface, give approximately the amount of occlusal surface or incisal edge, which is left. The procedure may be said to be a rough transference of the registering of a set of teeth according to Dahlberg and Westin's caries scale (Gunnar Dahlberg, 1940), carried out with a few classes. By this form of registering, it was only intended to give a rough conception of the number of teeth, with regard paid to the masticatory powers. The registering has therefore been carried out in summary fashion.

Set of teeth in adult men.

Table 14 gives only a general view of the number of teeth in 229 *adult men* from 20—45 years of age. The test subjects consisted of conscripts and older mobilized classes from Stockholm and environs. Figures are given of the maximal and the observed number of teeth. The figures in the table show that the number of teeth was fairly satisfactory, with small differences

TABLE 14.

Theoretical (T) and observed (N) number of teeth in 229 grown-up men.

Type of teeth	Number of teeth		
	T	N	N in % of T
Total number of teeth.....	7328	5815.25	79.4
Cutting teeth	2748	2698.00	98.2
Grinding teeth, of which	4580	3117.25	68.1
Wisdom teeth	916	396.50	43.3
Other grinding teeth	3664	2720.75	74.3

between calculated, maximal and actual number. Incisors and canines were missing only in 1.8 per cent of the calculated number, grinders — with the exception of wisdom teeth — were present in three-quarters, i. e. missing in 25.7 per cent, and the wisdom teeth were missing or had not come through in more than half, i. e. 56.7 per cent.

It is not always easy to decide if a tooth is a wisdom tooth or not. The author had not the opportunity of taking x-ray pictures in dubious cases. Consequently, the figures given here and in the following must be taken with some reservation.

If the set of teeth is evaluated in respect of mastication effectivity according to number of teeth, we run the risk of passing erroneous judgments. The loss of an occluding grinder deprives the antagonist tooth wholly or partially of its function. As has been said before, when the teeth are in an antagonist position, the loss of one is equal to the loss of two. In order to get a more detailed registration of the set of teeth, the number of contacts between occluding pairs of teeth has therefore been calculated in a way already given, namely estimating the approximate area of those tooth surfaces that meet in central occlusion. A survey of maximal and observed number of occlusion contacts is given in Table 15.

As was expected, it is found that the number of actual contacts is far lower than the maximal number. The difference is less for incisors, for which the actual number is 83.6 per cent, than for grinders (with the exception of the wisdom teeth); for these, only half, or 51.1 per cent, of the calculated contacts are found. The wisdom teeth seem to show in not quite a quarter, or 23.2 per cent.

TABLE 15.

Theoretical (T) and observed (N) number of contacts of teeth in 229 grown-up men.

Type of teeth	Number of contacts of teeth		
	T	N	N in % of T
Total number of teeth.....	7328	3808	52.0
Cutting teeth	1374	1149	83.6
Grinding teeth, of which	5954	2659	44.7
Wisdom teeth	1374	319	23.2
Other grinding teeth	4580	2340	51.1

Following the distribution of grinding teeth contacts in the material, it has been made into four groups with their limits at median and quartiles. A calculation shows that the lower quartile lies at 7.7 points, the median at 11.0 points, and the upper quartile at 15.9 points. According to this calculation, group I (extremely good sets of teeth) falls within the limits 26—16 points inclusive, group II (good sets of teeth) within the limits 15—11 points, group III (bad sets of teeth) within the limits 10—8 points, and group IV (extremely bad sets of teeth) within 7—0 points inclusive.

The limits are motivated by the actual distribution of the number of occlusion contacts among the individuals investigated. Theoretically, it would, of course, be possible to give other class limits; however, it has been considered necessary to let practical statistical viewpoints decide the grouping. The limits given make possible a statistical analysis of the material of a more satisfactory kind. In another material it may prove suitable to set other limits and to use more or fewer groups. The limits given now have, however, been used throughout the whole investigation, since comparison with the conditions in adult men is thereby rendered possible.

With regard to the grouping of the conscript material according to the number of occlusion contacts in the classes given above, it may be of interest to see how the average number of teeth is distributed within the different groups. (Cf. Table 16.)

The table shows that the average number of grinders gets fewer as the occlusion gets worse, while the number of incisors remains fairly constant. The difference in the average number of incisors in group I (extremely good sets of teeth) and group

TABLE 16.

Number of teeth in grown-up men, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	$M \pm \varepsilon(M)$	σ
Grinding teeth			
Group I: extremely good	63	17.33 ± 0.18	1.44
» II: good	60	15.13 ± 0.19	1.48
» III: bad	51	12.41 ± 0.24	1.71
» IV: extremely bad	55	8.82 ± 0.38	2.81
Cutting teeth			
Group I: extremely good	63	11.921 ± 0.039	0.311
» II: good	60	11.838 ± 0.055	0.423
» III: bad	51	11.676 ± 0.073	0.524
» IV: extremely bad	55	11.659 ± 0.123	0.911

IV (extremely bad sets of teeth) is not statistically significant (difference 0.26 ± 0.13). It ought to be expected that if the grinders are extensively defective, then the incisors, too, would be in less good condition. A calculation of the difference in standard deviation between incisors in extremely good and in extremely bad sets of teeth also shows that the difference is statistically significant (0.600 ± 0.091). When the grinders are poor, the incisors display an increased variability, indicating that they, too, are not so good in a number of cases, although the average number of incisors shows no significant difference between the groups.

Table 17 gives an idea of how far the average number of occlusion contacts agrees with the theoretical class midpoint in the different groups. The figures in the table show that the average number of occlusion contacts for group I (extremely good sets of teeth) is somewhat lower than the theorectical centre. The average number in the middle groups II and III (good and bad sets of teeth) agree well, on the other hand, while the average number for group IV (extremely bad sets of teeth) is rather higher than the theoretical centre.

The above grouping into four, with limits set by median and quartiles, gives groups with class ranges comprising different

TABLE 17.

Number of contacts of teeth in grown-up men, divided into groups with sets of teeth in varying condition. The class limits are: for group I, 26—16 mastication contacts, for group II, 15—11 mastication contacts, for group III, 10—8 mastication contacts, for group IV, 7—0 mastication contacts. Theoretical class midpoint = T. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	T	$M \pm \varepsilon(M)$	σ
Grinding teeth				
Group I: extremely good	63	21	18.54 ± 0.32	2.51
» II: good	60	13	12.57 ± 0.17	1.32
» III: bad	51	9	9.12 ± 0.12	0.86
» IV: extremely bad	55	3.5	4.95 ± 0.25	1.82
Cutting teeth				
Group I: extremely good	63	—	5.35 ± 0.16	1.29
» II: good	60	—	4.93 ± 0.21	1.60
» III: bad	51	—	4.90 ± 0.22	1.55
» IV: extremely bad	55	—	4.84 ± 0.25	1.85

numbers of occlusion contacts. Thus, 11 points correspond to group I, 5 points to group II, 3 points to group III and 7 points to group IV. A smaller number of points in the middle groups compared with the extreme groups should mean a greater variability in these latter. It is therefore not necessarily the case that, in reality, there is a sufficient number of sets of teeth with point totals tending towards the highest class limit in group I, and the lowest in group IV, to give a noticeable increase in the variability.

The figures in the table show, as a matter of fact, that the values for standard deviation and variation coefficient display shifts in these directions. The difference in the variability between the extreme groups is not statistically significant. On the other hand, that between the standard deviations for group I and group III is significant (difference 1.65 ± 0.21), as is also the one between group I and group II (difference 1.19 ± 0.25). We shall be discussing this problem again when investigating the mastication coefficient for these groups.

When evaluating the set of teeth with regard to the masticatory effectivity, the author has, for reasons previously given, proceeded on the belief that the number of occlusion contacts

gives a safer foundation for the estimation than the number of teeth. It has been seen that we get lower figures for the number of occlusal contacts compared with the number of grinding teeth. By comparing the figures in Table 16 with corresponding figures in Table 17, it is possible to get an idea of the relation borne by the average number of grinders in the different groups I—IV to the average number of contacts. The tables give figures for the number of grinders per occlusion unit; in extremely good sets of teeth, there are 0.93, in good sets of teeth 1.20, in bad sets of teeth 1.36 and in extremely bad sets of teeth 1.78. In a normal set of teeth, where none are missing, 0.80 of a tooth goes to each contact. The figure series shows that, as has already been pointed out, several teeth in a defective set have no functional significance. The calculated *contact coefficient* makes more exact comparisons possible, and the coefficient suggested here is to some extent suitable as a gauge of different sets of teeth.

The set of teeth can also be evaluated with regard to masticatory effectivity by measuring the impression of the two rows on a wax plate. In describing the method in Chapter 8, it was mentioned that misleading results might be obtained in isolated cases, both from incorrect biting on the wax and from the transference of the impression to a film and the measuring of the figures obtained in this way.

Obviously faulty specimens, due to biting wrong, have been discarded and taken afresh. As has been said before, a calculation has been made of the method's standard error in a single determination. This error is small (i. e. 2.7 %).

The estimation of the set of teeth according to the calculated number of occlusion contacts goes considerably quicker than the measurement of the occlusion surface area, and if this method proves sufficiently exact, it should perhaps be preferred, in certain cases, to the later one. Nevertheless, in the present investigation both methods have been used throughout.

Under all circumstances, however, information is needed as to how far the estimation of contacts and determination of surface agree. A calculation of the correlation between the number of occlusal contacts and the values of the occlusion surface area have been carried out on 226 conscripts and older mobilized classes. A correlation coefficient of $r = 0.86 \pm 0.02$ was obtained. As regards the schematized estimation of a set of teeth accor-

TABLE 18.

Occlusion surface in sq. mm. of grinding teeth in grown-up men, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	$M \pm \varepsilon(M)$	σ
Group I: extremely good	63	435.6 ± 11.2	89.0
» II: good	60	326.8 ± 8.4	64.9
» III: bad	51	250.0 ± 8.1	58.1
» IV: extremely bad	53 [1]	155.3 ± 8.9	64.7
Total	227	299.7 ± 8.3	125.7

ding to the number of contacts, in a small number of classes, it is surprising to find so good an agreement with the varying values obtained from the surface determinations. The high correlation shows that it is possible satisfactorily to classify the sets of teeth according to the number of occlusion contacts in the way described in Chapter 9.

Table 18 gives a survey of the average value of the occlusion surface area within the four groups, the grouping being done according to the number of occlusion contacts. The mean values in the table display good parallelism, in that equally large differences of about 100 sq. mm. are obtained between the groups. The figures show that the surface values exhibit a somewhat larger variability in per cent than the one found in evaluating the number of occlusion contacts for grinding teeth. This is probably due to the fact that the area of the occlusion surface varies in teeth with the same numeral. To facilitate the estimation of the number of contacts, the surfaces of the grinding teeth, as mentioned above, have been divided up into sections, two sections which meet on occlusion being given the value of a contact. It could not be taken into consideration here that the sections are, in some cases, on teeth with a comparatively large occlusal surface, and in other cases on teeth with a comparatively small one. It is therefore clear than we can expect a fairly large variability in the measured surfaces within the groups, since the grouping was done according to the number of contacts. Deviations of this sort counterbalance one another

[1] Information is lacking regarding 2 cases of 55.

TABLE 19.

Theoretical (T) and observed (N) number of teeth in 237 grown-up women.

Type of teeth	Number of teeth		
	T	N	N in % of T
Total number of teeth	7584	5887.50	77.6
Cutting teeth	2844	2804.00	98.6
Grinding teeth, of which	4740	3083.50	65.1
Wisdom teeth	948	266.75	28.1
Other grinding teeth	3792	2816.75	74.3

in such a way that the means run fairly parallel in both series of figures.

A comparison of the variability for the different groups yields differences of the same kind as in the investigation of the variation in the number of contacts. The difference between group I and group III is statistically significant (difference 30.9 ± 9.8).

Set of teeth in adult females.

Of the investigated adults, somewhat more than half, or 237 persons, consisted of *female* factory-hands in Stockholm from 16—45 years of age. All investigated persons have been included, and the material is probably fairly representative of the population group in question. A survey of the number of teeth in adult females is given in Table 19.

The figures in the table show an extremely small difference between the calculated maximal number of incisors and their actual number. They are missing only in 1.4 per cent of the calculated number. Grinders, with the exception of wisdom teeth, are present to three fourths, or 74.3 per cent, and wisdom teeth to one fourth, or 28.1 per cent of the calculated maximal number. As is seen on comparison with the figures in Table 14, there is surprisingly good agreement in the number of their teeth between men and women of corresponding ages. The only difference is found in the number of wisdom teeth, which in women are only present in 28.1 per cent, to 43.3 per cent in men.

A registering of the sets of teeth according to the number of grinder occlusion contacts gives values which also agree re-

TABLE 20.

Theoretical (T) and observed (N) number of contacts of teeth in 237 grown-up women.

Type of teeth	Number of contacts of teeth		
	T	N	N in % of T
Total number of teeth	7584	3929	51.8
Cutting teeth	1422	1150	80.9
Grinding teeth, of which	6162	2779	45.1
Wisdom teeth	1422	260	18.3
Other grinding teeth	4740	2519	53.1

markably well with the corresponding values in men. A survey of the number of contacts for incisors and grinders is given in Table 20.

In adult women, as in adult men, we find far lower figures for the actual number of grinder contacts compared with the calculated one. Incisors, on the other hand, are found in 80.9 per cent of the calculated number. The number of grinder contacts (with the exception of the wisdom teeth) amounts to half, or 53.1 per cent, and the number of contacts for wisdom teeth to not quite a fifth, or 18.3 per cent, of the maximal calculated

TABLE 21.

Number of teeth in grown-up women, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. n = number of persons. $M \pm \varepsilon(M)$ = mean $\pm$ standard error. σ = standard deviation.

Set of teeth	n	$M \pm \varepsilon(M)$	σ
Grinding teeth			
Group I: extremely good	61	16.15 ± 0.16	1.21
» II: good	76	14.11 ± 0.16	1.41
» III: bad	50	12.15 ± 0.24	1.71
» IV: extremely bad	50	8.37 ± 0.28	2.00
Cutting teeth			
Group I: extremely good	61	12.00	0
» II: good	76	11.934 ± 0.033	0.286
» III: bad	50	11.835 ± 0.058	0.411
» IV: extremely bad	50	11.465 ± 0.138	0.977

TABLE 22.

Number of contacts of teeth in grown-up women, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. Theoretical class midpoint = T. n = number of persons. $M \pm \varepsilon(M)$ = mean $\pm$ standard error. σ = standard deviation.

Set of teeth	n	T	$M \pm \varepsilon(M)$	σ
Cutting teeth				
Group I: extremely good	61	21	17.87 ± 0.22	1.73
» II: good	76	13	12.87 ± 0.15	1.35
» III: bad	50	9	9.16 ± 0.12	0.83
» IV: extremely bad	50	3.5	5.06 ± 0.23	1.62
Grinding teeth				
Group I: extremely good	61	—	4.92 ± 0.21	1.60
» II: good	76	—	4.91 ± 0.19	1.63
» III: bad	50	—	4.78 ± 0.28	1.95
» IV: extremely bad	50	—	4.76 ± 0.23	1.66

number. A comparison with the figures in Table 15 shows that the difference in the number of contacts between men and women is very small. The agreement is, in other words, surprisingly good.

In order to work out the distribution of the material in more detail, median and quartiles have been calculated for grinder contacts. The calculation gives about the same values as for men, namely the lower quartile at 8.5 points, the median at 11.7 points, and the upper quartile at 15.7 points.

Table 21 gives a survey of the average number of teeth in the different groups of extremely good to extremely bad sets of teeth (groups I—IV). The division has been made according to the number of occlusion contacts within the limits which were given for adult men.

The figures show that the number of persons in the different groups agrees on the whole with the number we find among adult men. The comparison between adult men and women shows good agreement as regards the mean number of teeth, the standard deviation, and the variation coefficient (cf. Table 17).

Figures for the average number of occlusion contacts in groups I—IV are given in Table 22.

The figures in the table show that, with regard to grinding teeth, the average number of contacts gets smaller as the occlu-

sion gets worse, while the average number of contacts for incisors keeps fairly constant. The averages agree well with the values obtained for men (cf. Table 17). For adult women, too, the same differences in the values for the standard deviation are found as for adult men. The difference between group I and group III is statistically significant. (Difference 0.90 ± 0.18). Other differences are not statistically significant.

It is possible to calculate the average number of grinders per occlusion unit from the values in Tables 21 and 22. For group I (extremely good sets of teeth) there are 0.90 grinders per occlusion unit, for group II (good sets of teeth) 1.09, for group III (bad sets of teeth) 1.32, and for group IV (extremely bad sets of teeth) 1.65. The figures agree well with the corresponding contact coefficients for adult men.

In the comparisons which have now been made between adult men and women of the same age, we thus find good accordance as regards both the number of teeth and the number of occlusion contacts. Taking into account the size of the materials compared, the possibility that a still larger material might reveal certain differences, in spite of the accordances, cannot be excluded. As, however, the accordance can be termed very good, and as the materials are not unduly small, there is hardly cause to expect very great differences. It has further been ascertained that the classification of the sets of teeth which was worked out from the state of affairs in 229 adult men, can be used for women of corresponding ages, in that medians and quartiles roughly coincide, so that the number of persons in the groups will be about the same.

It now remains to compare the average occlusion surface for adult women with the means obtained when investigating men of corresponding ages. A survey of such mean values in groups delimited according to the number of occlusion contacts, is found in Table 23.

As expected, we find throughout lower means for women than for men (cf. Table 18). The difference between the means is 26.3 ± 14.1 sq. mm. for group I (extremely good sets of teeth), 4.7 ± 12.1 sq. mm. for group II (good sets of teeth), 7.5 ± 11.1 sq. mm. for group III (bad sets of teeth), and 11.3 ± 12.2 sq. mm. for group IV (extremely bad sets of teeth). The differences are small and not statistically significant; in so far as there are any, they no doubt indicate that the teeth of an adult woman

TABLE 23.

Occlusion surface of the grinding teeth in sq. mm. in grown-up women, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	$M \pm \varepsilon(M)$	σ
Group I: extremely good	61	409.3 ± 8.6	67.0
» II: good	76	322.1 ± 9.1	79.4
» III: bad	50	242.5 ± 7.6	53.5
» IV: extremely bad	44[1]	144.0 ± 8.4	56.0
Total	231	295.1 ± 7.3	111.5

are smaller than those of an adult man. That the difference is greater for group I may possibly be due to the fact that the number of occlusion contacts for wisdom teeth is lower in women than in men. This fact is very marked in the values in group I (extremely good sets of teeth), while in the remaining groups, on the other hand, wisdom teeth are probably missing to a large extent in both sexes. (It should be remembered that we find wisdom teeth in men in 43.3 per cent of the calculated maximal number, and in women in 28.1 per cent.)

If we compare the four groups in the female material with one another, we find equal differences of about 90 sq. mm. between the means. In a comparison of the variability between men and women, we find somewhat lower values in the latter, but not statistically significant differences.

Set of teeth in old men.

With increasing age the number of teeth deteriorates on account of losses, defects and the like. The degree of deterioration is connected not only with age but also with dental treatment received, and therefore with social standards, too. The *older men* in the material investigated were taken from Stockholm workhouses. The amount of dental care they had received was very slight, so that the results of the investigation give a picture of conditions in sets of teeth which on the whole have not been the subjects of therapeutic measures.

[1] Regarding 6 cases of 50, information is lacking.

TABLE 24.

Theoretical (T) and observed (N) number of teeth in 258 older men.

Type of teeth	Number of teeth		
	T	N	N in % of T
Total number of teeth	8256	3748.50	45.4
Cutting teeth	3096	2012.50	65.0
Grinding teeth, of which	5160	1736.50	33.6
Wisdom teeth	1032	214.00	20.7
Other grinding teeth	4128	1521.00	36.8

Table 24 gives a survey of the number of teeth in 258 men from 45—80 years of age. Of these, 15 were under 50, and 24 over 70.

As expected, figures are found which indicate a relatively poor number of teeth. Of the calculated maximal number, incisors and canines are present to about two thirds, grinders with the exception of wisdom teeth to about one third, and wisdom teeth to less than one fourth. A comparison between the number of teeth in adult and older men (cf. Table 14) shows that incisors are lacking in the latter in 35 per cent of the calculated number, and in the former in 1.8 per cent. Grinding teeth are lacking in older men in 63.2 per cent and in younger men in 25.7 per cent. Wisdom teeth are missing in older men in 79.3 per cent of the calculated maximal number, compared with 56.7 per cent in adult men. It is noteworthy that the difference is so large for grinders, but considerably less for wisdoms. It has been assumed that wisdom teeth decay very soon after eruption, on account of inferior calcification. The comparison of the number of wisdom teeth in younger and older men suggests that, to a large extent (in half of the cases where such were found), they decay early, but that in an appreciable number of cases these teeth survive an early caries and have comparatively good powers of resistance, so that they are kept right up to a ripe old age. Because of the diagnostic difficulties previously mentioned, this conclusion must be taken with some reservation.

Of the 258 people submitted in Table 24, 101 of them from 50—75 years of age have been tested with regard to powers of mastication. The number of teeth in these persons was better, since they were selected. Under such circumstances, it is hardly

TABLE 25.

Number of contacts of teeth in older men, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. Theoretical class midpoint = T. n = number of persons. $M \pm \varepsilon(M)$ = mean $\pm$ standard error. σ = standard deviation.

Set of teeth	n	T	$M \pm \varepsilon(M)$	σ
Grinding teeth				
Group I: extremely good	15	21	18.80 ± 0.66	2.54
» II: good	24	13	12.71 ± 0.24	1.20
» III: bad	19	9	8.89 ± 0.19	0.81
» IV: extremely bad	43	3.5	4.23 ± 0.33	2.17
Cutting teeth				
Group I: extremely good	15	—	5.73 ± 0.21	0.80
» II: good	24	—	4.92 ± 0.28	1.35
» III: bad	19	—	5.05 ± 0.31	1.35
» IV: extremely bad	43	—	4.33 ± 0.21	1.36

of interest to give a detailed account of the nature of the teeth. In the grouping the same limits were used as for adult men.

A survey of the average number of occlusion contacts in the four groups is given in Table 25. The average number of occlusion contacts within the groups shows good agreement with the theoretical centre of the class for groups II and III. The groups I and IV show minor deviations, on the other hand.

The average number of grinders per occlusion unit gives, as is to be expected, rising figures: for group I, $0._{83}$ teeth, for group II, $1._{00}$ teeth, for group III, $1._{25}$ teeth and for group IV $1._{65}$ teeth.

The occlusion surface has also been determined for the older men. As Table 26 shows, 20 values are missing in group IV. The reason for this is that specimens taken from persons with few contacts were discarded, because the wax impressions were not so suitable for determining surface.

The values for the average occlusion surface are throughout higher than the values we found in adult men (cf. Table 18). The difference between adult men and older men is for group I (extremely good sets of teeth) $96._4 \pm 27._0$ sq. mm., for group II (good sets of teeth) $59._9 \pm 19._4$ sq. mm., for group III (bad sets of teeth) $44._7 \pm 22._4$ sq. mm., and for group IV (extremely bad

TABLE 26.

Occlusion surface of the grinding teeth in sq. mm. in older men, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	$M \pm \varepsilon(M)$	σ
Group I: extremely good	15	532.0 ± 24.6	95.1
» II: good	24	386.7 ± 17.5	85.8
» III: bad	19	294.7 ± 20.9	91.2
» IV: extremely bad	23[1]	198.7 ± 12.7	60.9
Total	81	338.6 ± 15.8	141.9

sets of teeth) 43.1 ± 15.5 sq. mm. The differences for groups I and II are statistically significant; that for group III, on the other hand, is not. In group IV the difference is statistically probable. The difference between adult and older men in extremely good and good sets of teeth is probably due to the fact that the grinders in the older men investigated were abraded to a greater extent. A tooth with the cusps worn down gives a larger wax impression than an intact tooth, but this does not mean that the smooth occlusal surface need necessarily be larger in actuality than the intact occlusal surface with high cusps. No difference in abrasion was found between groups III and IV, and no statistically significant difference in value between the occlusion surfaces was obtained.

If we finally investigate the variation, we find distinct differences as regards the number of contacts, so that the variability is larger in the extreme groups than in the middle groups. (Cf. Table 25). The difference between group I and group III is statistically significant (difference 1.73 ± 0.48).

If we look at the variability for the occlusion surface on the other hand, we do not get corresponding differences, and the differences are nowhere statistically significant. Here, then, there is a remarkable lack of parallelism between the number of occlusion contacts and the occlusal surface measured in sq. mm. The lack of agreement may possibly be supposed to be connected with the abrasion of teeth in the old, which constitutes yet another reason for variation.

[1] Regarding 20 cases of 43, information is lacking.

TABLE 27.

Theoretical (T) and observed (N) number of teeth in 45 older women.

Type of teeth	Number of teeth		
	T	N	N in % of T
Total number of teeth	1430	237.50	16.6
Cutting teeth	530	190.50	35.9
Grinding teeth, of which	900	47.00	5.2
Wisdom teeth	180	0	0
Other grinding teeth	720	47.00	6.5

Set of teeth in old women.

In giving an account of the investigation material in Chapter 8, it was said that it was not easy to find *older women* with their own teeth in almshouses. The author has been for material through two almshouses, together housing 620 women from 60—90 years of age, and among these has only been able to find a few with their own teeth. It is noteworthy that the number of teeth is considerably worse among older women than in the group of older men (cf. Table 24). It must, however, be said that the materials are not wholly comparable. The male material has been taken from a workhouse and does not include particularly ancient individuals, as men who are sickly and quite unable to work on account of age are transferred to almshouses. It may therefore well be that if a material of men, corresponding with that of the women as regards age, were investigated, an equally bad result would be obtained. In any case, less differences could certainly be expected than those expressed here by the figures. As it was, most of the older women had dentures. A small number had no teeth at all, and only 45 had any of their own left. An occasional tooth could sometimes be found in those with dentures, however, especially in the lower jaw as a support for the false ones. A survey of the nature of the teeth in the 45 women who had their own teeth is given in Table 27.

The table shows that the women investigated had few teeth, with large differences between the calculated maximal and the actual number. Of the total calculated number, only one sixth, or 16.6 per cent, were found in reality. There were no wisdom teeth at all, and only 6.5 per cent of the calculated maximal number of other grinders. As the figures show, the number of teeth

TABLE 28.

Number of contacts of teeth in older women, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. Theoretical class midpoint = T. n = number of persons. $M \pm \varepsilon(M)$ = mean $\pm$ standard error. σ = standard deviation.

Set of teeth	n	T	$M \pm \varepsilon(M)$	σ
Grinding teeth				
Group I: extremely good	10	21	18.90 ± 0.46	1.45
» II: good	17	13	12.18 ± 0.27	1.13
» III: bad	12	9	8.67 ± 0.19	0.65
» IV: extremely bad	11	3.5	4.55 ± 0.53	1.75
Cutting teeth				
Group I: extremely good	10	—	4.90 ± 0.48	1.52
» II: good	17	—	5.71 ± 0.11	0.47
» III: bad	12	—	5.25 ± 0.46	1.60
» IV: extremely bad	11	—	5.18 ± 0.33	1.08

in these women was such as to compel their being referred to group IV, i. e. extremely bad sets of teeth. It was further found that the grinder occlusion contacts were missing or else so few that the material did not lend itself to an investigation of the mastication effectivity. Only a few individuals could be used.

The investigation material had therefore to be sought elsewhere. At factories and other places of work, there proved to be great difficulties in getting older women with their own teeth for an investigation. The material that has been tested with regard to masticatory powers is mainly taken from the author's private practice.

The older women investigated belonged, as a rule, to the more well-to-do classes, and consisted of persons who had looked after their teeth. The number of teeth was comparatively good, and displayed small differences compared with the number in adult women, in spite of the difference in the average age between the two materials. Incisors were found to practically the whole of the calculated number, being absent in 3.1 per cent, grinders except for wisdom teeth to about three fourths or 72.5 per cent and wisdom teeth to about one fourth or 22.9 per cent.

The material is divided into four groups within the same limits for the point values as were used for adult men. A survey of

TABLE 29.

Occlusion surface in sq. mm. in older women, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	$M \pm \varepsilon(M)$	σ
Group I: extremely good	10	449.0 ± 20.7	65.4
» II: good	17	308.2 ± 13.0	53.8
» III: bad	12	200.8 ± 13.5	46.6
» IV: extremely bad	10[1]	132.5 ± 13.1	41.4
Total	49	274.8 ± 17.4	121.9

the average number of occlusion contacts within the four groups is given in Table 28.

In a comparison between the average number of occlusion contacts in adult and older women, we find them agreeing fairly well. In groups III and IV we have lower values for grinders and higher values for incisors. This contrast may possibly be explained by saying that, within certain limits, there is a connection between the lower number of grinder contacts and the higher number of incisor contacts, which means a decrease in the set of teeth and thereby a slight increase of the incisor contacts. This holds good of older men, too. This assumption is backed up by the fact that differences as concerns both grinders and incisors are only found in groups III and IV, i. e. in bad sets of teeth. The average number of grinders per occlusion unit shows 0.88 teeth for group I, 1.15 for group II, 1.24 for group III, and 1.79 for group IV.

The older women have not shown the same wear of the occlusal surface cusps as was found in the older men. Probably, therefore, we cannot expect such very great differences in the values for the occlusion surface area in a comparison of those in older women with corresponding values in adult women. A survey of the average values of the occlusion surface area in groups divided according to the number of grinder contacts, is given in Table 29.

The figures in the table show, when compared with the corresponding values for adult women in Table 23, that the average

[1] Regarding 1 case of 11, information is lacking.

TABLE 30.

Theoretical (T) and observed (N) number of teeth in 100 boys and girls at 13 years of age.

Type of teeth	Number of teeth		
	T	N	N in % of T
Total number of teeth	2800	2633.75	94.1
Cutting »	1200	1175.25	97.9
Grinding »	1600	1458.50	91.2

occlusion surface area in group I (extremely good sets of teeth) is larger, while in the other groups it is smaller. As the material is small and the differences not statistically significant, it is not possible to see whether there is any real difference in the area of the occlusal surfaces between adult and older women. It may be remembered that the average number of occlusion contacts is lower in older women just in groups III and IV; this should, in respect of the high correlation between occlusion surfaces and grinder contacts, give lower means for the occlusion surface in these latter groups.

Set of teeth in children.

In *children*, we have to reckon, as regards the number of teeth, with not altogether similar conditions for the sets as in adults, and this in certain respects prevents comparisons being made between the two. As is seen from the account of the investigation material in Chapter 8, some of the children investigated and tested for masticatory powers had permanent teeth, and some had their milk teeth. The material consists of schoolchildren from Stockholm, and can probably be regarded as representative in so far as all who came for investigation were included.

Table 30 gives a survey of the number of teeth in 100 *13-year-old children*, of which exactly half were boys and half girls. Taking into consideration the size of the material, it was not thought that a special differentiation of boys and girls would prove of interest.

The figures in the table show us that the difference between the actual number of teeth and the calculated maximal number is very small. Practically the whole of the total number is

TABLE 31.

Theoretical (T) and observed (N) number of contacts of teeth in 100 boys and girls at 13 years of age.

Type of teeth	Number of contacts of teeth		
	T	N	N in % of T
Total number of teeth	2600	1988	76.5
Cutting »	600	455	75.8
Grinding »	2000	1533	76.7

there, with the exception of incisors in 2.1 per cent and grinders in 8.8 per cent of the possible number, which in children of 13 amounts to 28. (44 children had 28 teeth.) Comparisons can now be made with the adults' teeth, as the wisdom teeth in tables for adults are kept separate from the other grinders. A comparison between 13-year-olds and adult men shows that the children investigated have a larger number of grinders. The difference is 16.9 per cent. On the other hand, the number of incisors in 13-year-old children is lower, with a difference of 0.7 per cent. This difference is small and may be due to chance.

The fact that most of the sets of teeth were complete has meant that the number of grinder occlusion contacts was very high, gaps in the rows being relatively rare. A survey of the actual and the calculated number of contacts is given in Table 31.

The figures in the table show the actual number of occlusion contacts for incisors to be missing in 24.2 per cent, and for grinders to be present to about three fourths — i. e. absent in 23.3 per cent — of the possible number. Contacts for adult men are missing in 48.9 per cent, and in 46.9 per cent for women. We find, in other words, about half of the grinder contacts in adult men and women, while in children there are about three fourths of the calculated number.

As the number of teeth among the 13-year-olds was largely good, the limits used in the material for grouping the sets into four could not be applied directly. A classification has been made following the distribution of grinder occlusion contacts in the material, with limits set at median and quartiles. The calculation shows that the lower quartile lies at 12.5 points, the median at 15.9 points, and the upper quartile at 18.1 points. According to this calculation, group I A (perfect teeth) falls within the

TABLE 32.

Number of contacts of teeth in thirteen-year-old children, divided into groups with sets of teeth in varying condition. The class limits are: for group I a, 20—19 mastication contacts, for group I b, 18—16 mastication contacts, for group II, 15—11 mastication contacts, for group III, 10—0 mastication contacts.

Set of teeth	n	T	$M \pm \varepsilon(M)$	σ
Grinding teeth				
Group I a: perfect	18	19.5	19.67 ± 0.11	0.49
» I b: very good	36	17	17.08 ± 0.14	0.84
» I a + I b: extremely good	54	.	17.94 ± 0.20	1.42
» II: good	37	13	12.84 ± 0.24	1.44
» III: bad	9	5	9.89	.
Cutting teeth				
Group I a: perfect	18	—	4.78 ± 0.50	2.10
» I b: very good	36	—	4.56 ± 0.43	2.56
» I a + I b: extremely good	54	—	4.63 ± 0.32	2.38
» II: good	37	—	4.59 ± 0.29	1.79
» III: bad	9	—	3.89	.

limits from 20—19 points inclusive, group I B (very good teeth) within the limits 18—16 points, group II (good teeth) within the limits 15—11 points, and group III (bad teeth) within the limits 10—0 points. For group II (good teeth), the same limits could be retained as used previously, i. e. the limits from 15—11 points. Group I (extremely good teeth) has been divided up into group I A (perfect teeth) and group I B (very good teeth), and group IV (extremely bad teeth) has been added to group III (bad teeth) to form one group.

In consideration of the very good number of teeth in the 13-year-old children investigated, relatively high values for the average number of occlusion contacts can be expected. Figures are given in Table 32.

In a comparison with corresponding averages for adult men and women, we find good agreement for the groups designated in the tables as extremely good, good and bad — i. e. groups I A and I B together, groups II and III. The adult group styled extremely bad teeth is not found among the older children investigated.

A calculation of the number of grinders per occlusion unit

TABLE 33.

Occlusion surface in sq. mm. in thirteen-year-old boys and girls, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 32. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	$M \pm \varepsilon(M)$	σ
Group I a: perfect	18	427.8 ± 10.5	44.4
» I b: very good	36	396.4 ± 9.0	54.3
» II: good	35[1]	311.4 ± 8.7	51.3
» III: bad	9	267.8	
Total	98	360.0 ± 7.6	74.9

for the different groups showed that practically all the teeth in group I had functional importance, and that, furthermore, only a relatively small number within groups II and III had no function at all. For group I A, the number of teeth per occlusion unit was 0.81, for group I B, 0.91, for group II, 1.05 and for group III, 1.17.

The investigated children had received dental treatment at school, and this no doubt contributed to their having a good number of teeth. The permanent teeth had as a rule come through completely, and many of the children still had the 6-year tooth. There is therefore reason to expect comparatively high values for the occlusion surface. A survey of the average occlusion surface for the four groups is given in Table 33.

The figures in the table show that the average value for the occlusion surface is high. The older children are found, in spite of the lack of wisdom teeth, to have biting surfaces which agree fairly well with the values displayed in adult men and women.

The youngest investigated children, i. e. 100 *7-year-old boys and girls,* had as a rule cut their 6-year tooth. The maximal number of teeth that a child can have at this age is 24, i. e. 20 milk teeth and 4 permanent teeth. A survey of the calculated and actual number of teeth is given in Table 34. The milk teeth and permanent teeth have not been kept separate here.

The figures in the table show that incisors are missing in 14.9 per cent of the calculated maximal number. The percentage figure is high, which is of course due to the fact that it is just

[1] Regarding 2 cases of 37, information is lacking.

TABLE 34.

Theoretical (T) and observed (N) number of teeth in 100 boys and girls at 7 years of age.

Type of teeth	Number of teeth		
	T	N	N in % of T
Total number of teeth	2400	1878.00	78.3
Cutting »	1200	1021.75	85.1
Grinding »	1200	856.25	71.4

at this age the child loses his first front teeth. Grinders (milk teeth and permanent teeth) are present to about three fourths, i. e. missing in 28.6 per cent, of the calculated number.

A survey of the number of occlusion contacts is given in Table 35.

The figures show that the number of occlusion contacts for grinders is high in relation to the number of teeth involved. Thus, in a comparison of percentages for the number of teeth and number of occlusion contacts between 7-year-old children and adult men (cf. Table 15), we find 17 per cent more contacts in the former, corresponding in both groups to about the same number of teeth. The comparison shows that the sets of teeth in 7-year-olds have relatively few gaps.

To discover whether the same limits for grouping the sets of teeth as were used for adult persons are suitable here, the distribution of the material was investigated with calculation of median and quartiles. This showed the lower quartile to lie at 6.8 points, the median at 9.3 points, and the upper quartile at 12.0 points. The distribution differs from the one found in the material for adult men and women, where the lower quartile

TABLE 35.

Theoretical (T) and observed (N) number of conctacts of teeth in 100 boys and girls at 7 years of age.

Type of teeth	Number of contacts of teeth		
	T	N	N in % of T
Total number of teeth	2000	1348	67.4
Cutting »	600	394	65.7
Grinding »	1400	954	68.1

TABLE 36.

Number of contacts of teeth in seven-year-old children, divided into groups with sets of teeth in varying condition. The class limits are: for group I, 20—16 mastication contacts, for group II, 15—11 mastication contacts, for group III, 10—8 mastication contacts, for group IV, 7—0 mastication contacts. Theoretical class midpoint = T. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	T	$M \pm \varepsilon(M)$	σ
Grinding teeth				
Group I: extremely good	8	18	16.00	.
» II: good	29	13	12.38 ± 0.22	1.21
» III: bad	35	9	8.89 ± 0.14	0.83
» IV: extremely bad	28	3.5	5.57 ± 0.21	1.10
Cutting teeth				
Group I: extremely good	8	—	4.13	.
» II: good	29	—	3.72 ± 0.25	1.33
» III: bad	35	—	3.97 ± 0.23	1.38
» IV: extremely bad	28	—	4.07 ± 0.24	1.27

lies at 7.7 points, the median at 11 points and the upper quartile at 15.9 points. The difference is nevertheless not so great that the same limits cannot be used in grouping the sets of teeth — namely, according to the number of occlusion contacts from 20—16 points for group I, 15—11 points for group II, 10—8 points for group III and 7—0 points for group IV.

We have now found a relatively high number of grinder occlusion contacts in proportion to the average number of the grinding teeth. It can be of interest to see how the average number of such contacts is distributed over the four groups, with reference to the grouping's having been done according to the same limits as were used for adults. A survey is given in Table 36.

The figures in the table show a surprising agreement in the average number of occlusion contacts for grinders in the four groups with corresponding figures for adult men and women (cf. Tables 17 and 22).

The occlusion surface has also been determined for the youngest children. A survey of the average surface is given in Table 37.

As expected, we find lower values compared with the corresponding ones for 13-year-olds. The difference for good sets of

TABLE 37.

Occlusion surface in sq. mm. in seven-year-old boys and girls, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 36. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	$M \pm \varepsilon(M)$	σ
Group I: extremely good	8	306.3	.
» II: good	29	263.1 ± 7.5	40.4
» III: bad	35	199.7 ± 4.8	28.2
» IV: extremely bad	26 [1]	144.0 ± 5.7	29.3
Total	98	212.4 ± 6.3	62.5

teeth (group II) is 48.3 ± 1.15 sq. mm., and is statistically significant. The total average difference is 147.6 ± 9.9 sq. mm.

In a comparison of the average value of the occlusion surface through the *whole of the investigation material*, we find the following values: for 13-year-old children 360.0 ± 7.6 sq. mm., (for older men, who, however, constitute a selected material, 338.6 ± 15.8 sq. mm.), for adult men 299.7 ± 8.3 sq. mm., for adult women 295.1 ± 7.3 sq. mm., (for a selected material of older women 274.8 ± 17.1 sq. mm.) and for 7-year-old children 212.4 ± 6.3 sq. mm. We find the greatest difference between 13-year-old children and 7-year-old children. The total average value for the occlusion surface for adult men and women lies about halfway between the values for 13-year-olds and 7-year-olds. The older men and women investigated are not representative for the respective age groups, so that a comparison with their values is of no very great interest.

It was thought unnecessary to compare the results obtained by the author with those in other investigations which have been carried out into the nature of the teeth in the average population of Sweden. Such investigations have been made to get some information with regard to the occurrence of caries, but are not intended to throw light on the sets of teeth from a functional point of view. On the whole, the materials have not been submitted to any close statistical analysis, so that the figures obtained cannot be compared with those submitted here.

[1] Regarding 2 cases of 28, information is lacking.

Chapter 12.

The number of chews in persons of different age and sex, and with different sets of teeth.

The number of times a mouthful is chewed before being swallowed depends first and foremost on its character, i. e. it is influenced by sensations deriving from the degree to which the mouthful is reduced. Different food substances are chewed for different lengths of time. Conscious acts of will probably do not play such a very large part in normal chewing, even if such factors may be thought to have some influence when it is a question of special tests. It can be assumed without further discussion that more or less constant habits are formed in chewing. One person may chew carelessly, i. e. only a few times, another may chew each mouthful a large number of times. There are, in principle, two ways in which these habits can be thought to be determined: food of a certain sort may be chewed until a certain degree of reduction is reached, or it may be chewed a certain number of times, with not so much attention paid to the result obtained.

If the degree of reduction is the deciding factor, we should expect great average differences between persons with good and bad sets of teeth. Those with bad sets ought, as a rule, to compensate the lowered effectivity due to loss of teeth by chewing longer, for a larger number of chews must be needed to reach a result comparable with that from good sets. We should find a certain variability for persons with the same sort of teeth, but this ought to be less than the one obtained in a population where the sets of teeth, too, vary. In so far as the question is one of habits, the variation in the number of chews when a given individual chews successive portions of one and the same type of food substance should be comparatively small.

If, on the other hand, the more or less fixed habits refer to the number of chews, this number should, once the habits have been formed, be fairly independent of the conditions in the sets

of teeth. Persons with poor sets should, on an average, chew the same number of times as those with good sets. We would further expect to find the variation in the number of chews for persons with the same sort of teeth to be about as large as the one in a population where the sets of teeth vary, also. Then, too, we expect a relatively small variation when one person chews successive mouthfuls of a selected substance.

It is, of course, possible that the way in which an individual chews is determined both by factors referring to the number of chews, and factors conditioned by sensations due to the mouthful's degree of reduction. These principles will be taken into account in the investigation in the following pages of the number of chews used in the mastication tests by persons of different ages, different sex, and with different sets of teeth. Before these problems are discussed, however, an account will be given of investigations, made to get an idea of the importance the character of the test material has for the number of chews, and also of investigations into how far the test corresponds to chewing under normal circumstances.

Chewing materials of different types.

Now, when chewing food, the number of chews varies with the consistency of the food and the size of the moutfuls. In the investigation of test material of different consistency, described in Chapter 3, a small number of conscripts were made to chew in succession approximately the same amount of gelatin, carrot, white of egg, synthetic rubber and indiarubber. The test subjects, half of which had good sets of teeth, and half bad, were allowed to chew the different portions for as long as they themselves wanted. Table 38 gives figures showing how test portions of different consistency are chewed.

The table shows that white of egg is on an average chewed a very small number of times, after which the test subjects consider it ready to swallow. Indiarubber, on the other hand, seems hard to chew, and takes a relatively long time, though as the number of tests is small, the differences compared with other materials (with the exception of white of egg) are not statistically significant. When the sets of teeth are bad, we find no differences of any great importance between the other substances, i. e. gelatin, carrot, and synthetic rubber. Subjects with good

TABLE 38.

Number of chews in mastication of materials of different kinds. Regarding class limits, see Table 17. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Material	n	$M \pm \varepsilon(M)$	σ
Extremely good set of teeth: not swallowed tests			
Gelatin 10 %	41	49.8 ± 2.6	16.5
» 15	41	53.2 ± 2.3	14.7
» 20	41	55.4 ± 2.4	15.6
Carrot	41	41.5 ± 2.4	15.6
White of egg	41	16.2 ± 1.0	6.5
Synthetic rubber	33	43.6 ± 3.2	18.2
Indiarubber	11	63.5 ± 7.8	25.9
Extremely good set of teeth: swallowed tests			
Gelatin 15 %	27	54.3 ± 3.8	19.9
Carrot	28	39.1 ± 2.9	15.4
White of egg	28	12.9 ± 0.9	4.5
Bad set of teeth: not swallowed tests			
Gelatin 10 %	42	47.1 ± 3.0	19.4
» 15 %	42	55.4 ± 3.2	20.5
» 20 %	42	58.4 ± 3.2	20.8
Carrot	42	55.4 ± 2.8	17.9
White of egg	42	16.4 ± 1.0	6.6
Synthetic rubber	36	56.1 ± 3.1	18.5
Indiarubber	12	73.1 ± 6.9	23.7
Bad set of teeth: swallowed tests			
Gelatin 15 %	28	60.8 ± 5.1	26.8
Carrot	28	51.7 ± 2.7	14.4
White of egg	29	14.3 ± 1.2	6.5

teeth stop chewing synthetic rubber and carrot after a somewhat fewer number of chews than are taken for gelatin. The difference is statistically significant between carrot and 20 per cent gelatin (13.9 ± 3.4), and statistically probable between synthetic rubber and 20 per cent gelatin (11.8 ± 4.0). The figures show, however, that there is a great difference in the number of chews which different people take to chew a material. The figures seem to imply that the standard deviation is greater in poor sets of teeth than in good ones, but these differences are not statistically significant.

A comparison between the number of chews in good and bad

sets of teeth shows good agreement for white of egg (difference 0.2 ± 1.4), indiarubber (difference 9.6 ± 10.4), and 15 per cent gelatin (difference 2.2 ± 3.9). A similar comparison using synthetic rubber gives a probable difference (12.5 ± 4.5), and only for carrot do we find a statistically significant difference (13.9 ± 3.7) in testing (but not in chewing and swallowing). This result, however, must be taken with a certain amount of reservation, because it has been difficult to get chewing pieces of the same size at different occasions (as a matter of fact the chewing pieces for the two groups were cut by different persons) and, furthermore, the quality of the carrots may have been different in different samples.

The investigation shows that the number of chews increases if the material is difficult to chew. We get the impression that their number is possibly slightly raised in chewing with poor sets of teeth. This question will be discussed in more detail in the following pages.

Chewing in testing and swallowing.

An investigation has also been made to see whether the test subjects chewed the second and third test portion according to instructions received. A small number of persons were told to chew pieces of a certain size, consisting of gelatin, carrot, and coagulated white of egg, until the mass felt *ready* to swallow, and were also given a corresponding number of pieces to chew *and* swallow. The number of chews was counted each time. To avoid systematic errors in the number of chews the order of these two processes was varied, as also the order of the different materials of gelatin, carrot and white of egg.

Table 38 also gives figures of the difference between the average number of chews in chewed and swallowed portions on the one hand, and in only chewed portions on the other. The figures agree well.

The figures obtained in double tests have further been statistically analysed, so that the separate differences were calculated between consecutive portions. The means of the differences were then calculated. The results are shown in table 39. We can see from the figures that the number of chews in the test-chewing and in the chewing with swallowing agrees well. Statistically significant differences are found only for white of

TABLE 39.

Differences in number of chews when the pieces are swallowed and when they are chewed for testing. + means that the number of chews in swallowing is greater than the number in testing. n = number of persons. $D \pm \varepsilon(D)$ = mean of the differences ± standard error.

Material	n	$D \pm \varepsilon(D)$
Extremely good set of teeth		
15 % gelatin	27	-0.8 ± 3.6
Carrot	28	-2.6 ± 1.5
White of egg	28	-3.5 ± 1.0
Bad set of teeth		
15 % gelatin	28	$+3.8 \pm 3.7$
Carrot	28	-0.5 ± 2.9
White of egg	29	-2.8 ± 0.7

egg: in good sets of teeth 3.5 ± 1.0, and in bad ones 2.8 ± 0.7. Though statistically significant, they are so small that they can be looked upon as having no importance. The results are surprising, as distinct differences might have been expected. With food, as we know, a person chews and swallows alternately until the mouthful has gone down. When a test portion is chewed until it feels ready to swallow, it does not get smaller during the process but, on the contrary, 'grows' in the mouth. It should therefore be difficult to determine when the chewed mass is ready to swallow — when, that is to say, one should stop chewing. The investigation indicates that, as far as the number of chews are concerned, the test subjects are not influenced by the successive diminution of what they have in their mouths in the one test, and by its successive »increase» in the other. The instructions given for mastication tests II and III seem, therefore, possible to follow correctly.

Chewing with more or less defective set of teeth.

It is now of great interest to discover more definitely whether, as there is most reason to expect, a deterioration in the number of teeth and a decrease of occlusion contacts lead persons to compensate for poor powers of mastication by chewing a larger number of times.

TABLE 40.

Number of chews in grown-up men in mastication of test portions. Distribution with regard to sets of teeth in varying condition. (Cf. Table 17.)
n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error.
σ = standard deviation.

Set of teeth	n	Mastication test					
		I		II		III	
		$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ
Group I: extremely good	63	60.0 ± 3.1	24.6	63.2 ± 3.4	26.9	68.6 ± 3.4	27.2
» II: good	60	60.2 ± 3.7	28.5	65.1 ± 3.9	30.6	66.9 ± 3.7	28.7
» III: bad	51	61.5 ± 3.3	23.6	71.8 ± 3.8	27.4	70.7 ± 3.6	25.5
» IV: extremely bad	55	65.5 ± 4.5	33.1	65.0 ± 4.3	32.0	65.2 ± 3.7	27.3
» I—IV:	229	61.6 ± 1.8	27.8	66.2 ± 1.9	29.5	67.8 ± 1.8	27.3
» I—IV: mastication test II + III: $n = 458$; $M = 67.0 \pm 1.3$; $\sigma = 28.4$							

The number of chews has therefore been counted in each test in the whole of the investigation material, and the average number of chews is given in the statistical treatment of the first, second, and third tests in the groups I, II, III, and IV. This makes it possible to compare the number of chews in children and adult and old men and women, with good and bad sets of teeth. As has been said before, the persons investigated were given standardized portions to chew. The instructions which were given in the mastication tests, and which were described in Chapter 9, signified that the first portion (in subsequent tables denoted test portion I) is chewed as the subject chooses, the second and third portions (II and III) are chewed until they feel ready for swallowing in the same way as if they were food.

Table 40 gives a survey of the average number of chews taken for standardized portions in tests I, II and III, by 229 conscripts and older mobilized classes with extremely good, good, bad, and extremely bad sets of teeth.

The figures show that there is remarkable agreement in the average number of chews in different sets of teeth, i. e. between the groups I, II, III, and IV. For test III, the difference in the average number of chews between groups I and IV is 3.1 ± 5.0. The figures show, further, that there is great variation in the number taken by different persons for the standardized portion. The values for the standard deviation and the variation

TABLE 41.

Number of chews in grown-up women in mastication of test portions. Distribution with regard to sets of teeth in varying condition. (Cf. Table 17.) n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	Mastication test					
		I		II		III	
		$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ
Group I: perfect	61	63.3 ± 2.8	22.0	54.8 ± 3.2	24.8	55.1 ± 2.9	22.4
» II: very good	76	63.9 ± 3.1	26.9	59.0 ± 2.4	20.8	58.8 ± 2.5	21.8
» III: bad	50	67.0 ± 3.8	27.2	58.3 ± 3.6	25.3	58.6 ± 3.3	23.4
» IV: extremely bad	50	77.0 ± 4.6	32.8	61.5 ± 3.3	25.5	62.0 ± 3.6	25.3
» I—IV:	237	67.2 ± 1.8	27.7	58.3 ± 1.5	23.5	58.5 ± 1.5	23.2
» I—IV: mastication test II + III: $n = 474$; $M = 58.4 \pm 1.1$; $\sigma = 23.4$							

coefficient nevertheless agree well in a comparison between sets of teeth of different types. The differences for the standard deviation between the groups are not statistically significant.

Table 41 gives figures of the average number of chews taken by 237 adult women. As with the men, we find the mean number of chews in the groups I, II, III, and IV agreeing well. If we take, for comparison purposes, mastication test III, where the second chewing is continued till the portion feels ready to swallow, we find that the women have, on the average, chewed a rather fewer number of times than the men (cf. Table 40). The differences are small, however, and they are not quite statistically significant. For group I the difference is 13.5 ± 4.5, for group II 8.1 ± 4.5, for group III 12.1 ± 4.9 and for group IV 3.2 ± 5.2.

As, in both cases, the mastication tests have been made with standardized portions, the author expected to find statistically significant differences with, on an average, more chews for the women, since anatomical and perhaps conventional reasons make it more likely that they should be in the habit of taking smaller mouthfuls. A large mouthful needs more chewing than a small one, and the standardized test portions do constitute a relatively large mouthful, for the investigated women.

The result obtained in the investigation of the number of chews in adult women backs up the conclusion that, in food moderately

TABLE 42.

Number of chews in older men in mastication of test portions. Distribution with regard to sets of teeth in varying condition. (Cf. Table 17.)
n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error.
σ = standard deviation.

Set of teeth	n	Mastication test					
		I		II		III	
		$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ
Group I: extremely good	15	71.9±6.0	23.2	60.9±5.1	19.6	63.4±4.5	17.5
» II: good	24	112.8±7.5	36.9	69.0±4.5	22.1	69.1±4.3	21.1
III: bad	19	98.0±9 2	40.2	69.3±5.3	23.3	69.5±5.3	22.9
» IV: extremely bad	43	90.9±4.7	30.8	66.4±3.9	25.4	68.1±3.5	23.3
» I—IV:	101	94.6±3.5	35.1	66.8±2.3	23.2	67.9±2.1	21.6
» I—IV: mastication test II + III: $n = 202$; $M = 67.3 \pm 1.6$; $\sigma = 22.4$							

difficult to chew, those habits are very firmly fixed which refer to a tendency to chew a certain number of times before swallowing, which tendency varies from person to person, but is fairly fixed for a single individual. This habit is not shaken by subsequent defects in the set of teeth. In other words, a poor set of teeth is not compensated by chewing longer. We find the same thing in both older men and older women, i. e. good agreement

TABLE 43.

Number of chews in older women in mastication of test portions. Distribution with regard to sets of teeth in varying condition. (Cf. Table 17.)
n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error.
σ = standard deviation.

Set of teeth	n	Mastication test					
		I		II		III	
		$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ
Group I: extremely good	10	69.6±4.1	13.0	49.7±7.2	22.8	51.3±6.8	21.5
» II: good	17	76.5±5.2	21.5	62.9±4.5	18.7	66.7±4.8	19.8
» III: bad	12	67.8±7.3	25.4	73.2±8.0	27.8	74.6±8.2	28.5
» IV: extremely bad	11	72.4±6.7	22.2	66.3±7.6	25.3	68.9±7.1	23.6
» I—IV:	50	74.3±2.9	20.7	63.5±3.4	23.8	66.0±3.4	23.7
» I—IV: Mastication test II + III: $n = 100$; $M = 64.7 \pm 2.4$; $\sigma = 23.8$							

TABLE 44.

Number of chews in thirteen-year-old children in mastication of test portions. Distribution with regard to sets of teeth in varying condition. (Cf. Table 32.) n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	Mastication test I		II		III	
		$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon M$	σ	$M \pm \varepsilon M$	σ
Group I a: extremely good	18	63.7 ± 3.2	13.5	50.6 ± 3.7	15.7	52.2 ± 3.9	16.6
» I b: » »	36	58.0 ± 3.4	20.4	58.7 ± 2.9	17.1	58.6 ± 2.6	15.5
» II: good	37	64.0 ± 2.7	16.7	55.4 ± 2.4	14.8	56.5 ± 2.5	15.4
» III: bad	9	69.9	.	50.8	.	53.9	.
» I—III:	100	62.3 ± 1.8	18.3	55.3 ± 1.6	16.4	56.3 ± 1.6	15.5
» I—III: Mastication test II + III: $n = 200$; $M = 55.8 \pm 1.1$; $\sigma = 16.0$							

in the number of chews in good or in more or less defective sets of teeth. (Cf. Tables 42 and 43.) The same results are also obtained in a comparison of sets of varying excellence among 13-year-old children (Table 44), and among 7-year-olds (Table 45). Nowhere do we find statistically significant differences between the different teeth sets. Under such circumstances we

TABLE 45.

Number of chews in seven-year-old children in mastication of test portions. Distribution with regard to sets of teeth in varying condition. (Cf. Table 36.) n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	Mastication test I		II		III	
		$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ
Group I: extremely good	8	45.0	.	42.5	.	46.5	.
» II: good	29	51.8 ± 3.4	18.2	52.9 ± 3.2	17.4	52.3 ± 2.8	15.2
» III: bad	35	50.9 ± 2.6	15.7	51.9 ± 2.6	15.3	49.1 ± 2.8	16.8
» IV: extremely bad	28	45.3 ± 2.8	15.0	46.5 ± 3.0	15.8	47.9 ± 3.0	15.9
» I—IV:	100	49.1 ± 1.6	16.5	49.9 ± 1.6	16.2	49.5 ± 1.6	15.7
» I—IV: Mastication test II + III: $n = 200$; $M = 49.7 \pm 1.1$; $\sigma = 15.9$							

may be justified in lumping together the results from the different groups, which figures are also given in the tables.

It is now of interest to compare mastication test I with tests II and III. As has been said before, in the first test the subject was allowed to chew as he liked. In II and III he was told to chew the portion till it felt ready to swallow. Under such circumstances we may expect differences between the first test and the other two. A difference of this kind is not found for adult men. For adult women there is a small difference, which is all the same statistically significant (difference 8.8 ± 2.1); older women, on the other hand, only show a probable difference: here, the material is smaller, and the standard error larger (difference 9.6 ± 3.8). For older men we find a very pronounced difference (difference 27.3 ± 3.8). As has been said before, these latter had been admitted to workhouses, and were therefore to a certain extent accustomed to act on orders; in a number of cases the author was able to see how they patiently went on and on chewing, waiting for permission to spit the mouthful out. This fact probably explains the great deviation. If, finally, we look at the children, we find a statistically significant difference among the 13-year-olds. The first test has been better chewed (difference 6.5 ± 2.1). For 7-year-olds, on the other hand, there is good agreement; at this age, they have obviously not let their habits be disturbed just because they were being subjected to a test, which must, to a certain extent, seem a bit of a strange one.

Chewing in regard to age and sex.

It is now of interest to try, by using the lumped together material, to see whether it has been possible to find minor differences between the groups investigated. If we, then, in the first place compare adult men and women, we find a small statistically significant difference (difference 8.6 ± 1.7). On the other hand, if we compare older men with younger men, and older women with younger women, we find neither significant nor probable differences. If, finally, we compare 13-year-olds with adult men, we get a statistically significant difference (difference 11.2 ± 1.7), but there is no difference in a comparison with adult women. An interesting thing is that 7-year-olds chew a smaller number of times than either adult men or women; yet the difference compared with the latter is statistically significant (dif-

ference 8.7 ± 1.6). Finally, the difference between 13-year-old and 7-year-old children is statistically significant, amounting to 6.1 ± 1.6. This possibly indicates that the chewing habits, which must of course be formed during childhood have not yet become fully fixed at the age of 7. It may be that 7-year-olds adapt themselves to the character of the food to be chewed more than is the case later in life. At any rate it can be affirmed that 7-year-olds chew more 'carelessly' than do those who are older.

When comparing children and adults it must be remembered that the children were tested with a smaller test portion. To get an idea of the influence of this factor, special tests on adults have been carried out. The same person has been tested with test portions of both sizes. In 30 cases the average difference between these two tests is found to be 12.6 ± 1.5 chews, or 19.4 per cent. This is almost exactly the same difference as between 13-year-olds and adult men. Therefore, if allowing for the difference in the size of the tests portions, there is no reason to assume any difference between 13-year-olds and adults. The difference between children of 7 and 13 years of age, however, stands, as they have been tested with test portions of the same size.

From a theoretical point of view it is of course to be expected that the size of the test portions should have a certain influence which the author previously has pointed out. It has not been possible to enlarge the investigation by going deeper into this problem.

Our concern is, now, to get an idea of the variability. To say that people have different habits is easy enough. One chews a few times and eats quickly and 'carelessly', the other chews long and hard and eats slowly. There is actually great variability also. For adult men, it amounts to 28.4 ± 0.94 chews, i. e. to 42.4 per cent. It is somewhat smaller in adult women, being 23.4 ± 0.76 chews, i. e. 40.0 per cent. The difference between the standard deviations is statistically significant. In both materials, however, the standard deviation is so great that the distribution must be skew. (It can, of course, never vary further below the mean than to nearly 0 chews.) A survey is therefore given in Table 46 of the distribution in adult men and women for the different teeth groups. The distribution shows that there are no values beyond 2 σ below the mean; above it, however, the range of variation approaches 3.5 σ. In other words, the distribution is moderately

TABLE 46.

Distribution of number of chews in grown-up men and women (groups with different sets of teeth are joined). The class interval is for men: 0.5 $\sigma = 13.7$ chews; for women: 0.5 $\sigma = 11.6$ chews. M = mean. σ = standard deviation.

Sex	$-M+$											Total
	$2\sigma\leftarrow$	$1.5\sigma\leftarrow$	$1\sigma\leftarrow$	$0.5\sigma\leftarrow$	$\rightarrow 0.5\sigma$	$\rightarrow 1\sigma$	$\rightarrow 1.5\sigma$	$\rightarrow 2\sigma$	$\rightarrow 2.5\sigma$	$\rightarrow 3\sigma$	$\rightarrow 3.5\sigma$	
Men:												
Number	8.0	28.8	49.2	39.2	36.8	29.2	15.1	11.7	8.0	3.0	.	229
%	3.5	12.6	21.4	17.1	16.1	12.8	6.6	5.1	3.5	1.3	.	100.0
Women:												
Number	4.0	27.7	54.6	45.8	45.7	24.4	16.6	5.6	5.6	5.0	2.0	237
%	1.7	11.7	23.0	19.3	19.3	10.3	7.0	2.4	2.4	2.1	0.8	100.0

skew. Under such circumstances, it is possible to say that the number of chews varies around 60—70 in adult men and women, and that the range of variation goes down to 12—15, and up towards 140—165. The figures thus show that there is very great variation in the chewing habits which characterize different persons. We get a similar variation range for children and old people, also. The variation coefficient keeps at 30—35 per cent. In consideration of the fact that 7-year-olds chew, on an average, a fewer number of times than other groups, it is interesting to find that the standard deviation expressed in number of chews is appreciably smaller for them than for the others. The decrease is fairly proportionate to the decreased average number of chews, so that the variation coefficient amounts to 32.1 per cent.

Individual and interindividual variability.

With the great variability in chewing habits as a background, we are now motivated in investigating how far we really are dealing with stabilized habits. A habit of chewing in a certain way can be more or less firm. An individual can, on an average, tend to chew a certain number of times, but this does not prevent him from chewing one and the same substance rather more one time, and rather less another. A gauge of the individual variation is obtained from the differences between mastication tests II and III, which were, as we know, made in the same way. The result

TABLE 47.

Average difference (M) and standard error (ε) between number of chews in grown-up men and women in mastication tests II and III, and from the differences calculated standard deviation (σ_i) and variation coefficient (V) for a single individual. — means, that the number of chews in mastication test II is smaller than the number in mastication test III. n = number of persons.

Sex	n	$M \pm \varepsilon(M)$	σ_i	V
Men	229	-1.64 ± 1.05	11.3	16.9
Women	237	-0.19 ± 0.71	7.7	13.3

of calculations based on these differences will be found in Table 47.

The table shows there to be no statistically significant differences between the second and the third test portion. It can further be seen that the individual variation is considerably less than the one distinguishing adult men and women. For men it is 11.3 ± 0.53 chews, and for women 7.7 ± 0.35 chews. This actually means that an individual can vary to a certain extent in his chewing from one time to another. Compared with the great variation characterizing the population, however, the individual variation may be termed small. There is, incidentally, a minor difference between men and women, which is statistically significant. It amounts to 3.6 ± 0.64.

To get a more definitive idea of the relation between the total variation and the variation in the course of individual mastication, we make a division according to G. DAHLBERG (1926), using the formula $\sigma_t = \sqrt{\sigma_i^2 + \sigma_p^2}$ where σ_t = the total standard deviation, σ_i = the individual standard deviation obtained from differences between two tests, and σ_p = the interindividual standard deviation which is to be calculated. We then find that the variability that remains after subtracting the individual variation amounts to 26.1 ± 1.7 for men, and to 22.1 ± 1.4 for women. This implies that the great variation in the number of chews which is found in a population is in very small measure conditioned by the individual way of chewing a different number of times on different occasions. It *is* conditioned in considerable measure by different chewing tendencies in different persons. In other words, we are fully justified in talking of quite firm chewing habits;

the difference between different individuals as regards this is very great — perhaps greater than might beforehand be expected.

It now remains to compare the variation in the whole population with the variation distinguishing the different teeth groups. A comparison for men (Table 40) and women (Table 41) shows good agreement between the standard deviation for the lumped together material and that for the different teeth groups. There are no statistically significant differences anywhere. This agrees with what was advanced by way of introduction — namely, that if the number of chews is determined by personal habits, the same variation should be obtained when persons are investigated with sets of teeth of a certain type, as when material is investigated with sets of teeth of varying types. If the number of chews was influenced by the degree to which the mouthful is reduced, tests should reveal greater variability in a population composed of persons with sets of teeth of very varying type than in a narrow class of persons with similar sets of teeth.

By way of *summary* it may be said that a statistical treatment of the material has showed there to be fixed habits as to the number of times a mouthful is chewed, which habits are admittedly influenced by *great* differences of consistency in different food substances, but are not noticeably affected, by deterioration in the set of teeth brought about by partial or total losses. The mastication habits do not seem to be fully formed by the age of 7, but they remain stable at any rate from 13 up to a considerable age. Differences can be found between men and women, but they are very small ones. An individual varies somewhat in his chewing, but this variability is small compared with the one conditioned by the dissimilarity between the members of a population. Here, one person may be content with a few chews before he is ready to swallow, while another chews extremely carefully and for a long time before he has finished with his mouthful. Finally, it has been found that the variation in the number of chews between people with sets of teeth of the same type, is as great as the variation in the total population, where the sets of teeth also vary to a high degree.

Chapter 13.

The average reduction of the test portion in persons of different age and sex, and with different sets of teeth.

After having investigated the number of times persons with complete and with more or less defective sets of teeth chew the standardized test portion, it remains to attempt an analysis of the effect of the chewing. It is then of primary interest to try and get, by means of mastication coefficients, an idea of the average masticatory effectivity in groups of persons with different sets of teeth.

In an account of the masticatory effectivity, it would be natural to begin with children and then pass on to adult and old persons. Earlier in this work, the author has dealt with adult men and women first, as these groups are relatively large and can be regarded as representative. In other words, they constitute a suitable starting-point for a comparison with children and old people. In the following account, therefore, the investigation material will be treated in the same order.

The mastication coefficient suggested in this work is based on the assumption that the irregularly shaped particles correspond to regular polyhedrons. It is true that, on special investigation, the assumptions made have proved fairly correct, but as there is nevertheless a certain element of uncertainty in the conditions on which calculations of the mastication coefficient are based, tables of the distribution of the fractions are given in the first place.

Mastication effect in adult men and women.

Figures of the average distribution of the *fractions* in adult men with extremely good, good, bad and extremely bad sets of teeth are given in Table 48. The values give the size of the fractions obtained in chewing till the mouthful feels ready to swallow.

TABLE 48.

Average distribution of the fractions in grown-up men and women, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error.

Fraction	Set of teeth			
	Group I: extremely good	Group II: good	Group III: bad	Group IV: extremely bad
	$M \pm \varepsilon(M)$	$M \pm \varepsilon(M)$	$M \pm \varepsilon(M)$	$M \pm \varepsilon(M)$
	Men			
1	2.13 ± 0.19	0.92 ± 0.07	0.59 ± 0.05	0.61 ± 0.06
2	4.03 ± 0.26	2.15 ± 0.16	1.33 ± 0.10	1.24 ± 0.11
3	4.44 ± 0.19	3.18 ± 0.19	2.26 ± 0.15	1.98 ± 0.14
4	65.54 ± 3.10	63.35 ± 3.25	51.06 ± 3.38	42.75 ± 2.67
5	28.60 ± 1.35	35.40 ± 1.36	33.43 ± 1.42	29.15 ± 1.41
6	11.52 ± 0.82	18.23 ± 0.80	20.22 ± 0.97	20.09 ± 0.98
7	5.43 ± 0.57	8.65 ± 0.59	11.39 ± 0.60	12.25 ± 0.67
8	2.32 ± 0.33	4.85 ± 0.48	6.14 ± 0.47	5.96 ± 0.41
9	1.11 ± 0.18	1.98 ± 0.24	2.57 ± 0.31	2.82 ± 0.26
10	0.79 ± 0.22	1.55 ± 0.26	1.75 ± 0.31	2.71 ± 0.40
	$n = 63$	$n = 60$	$n = 51$	$n = 55$
	Women			
1	2.15 ± 0.13	1.31 ± 0.09	0.88 ± 0.09	0.74 ± 0.06
2	3.74 ± 0.16	2.56 ± 0.14	1.81 ± 0.15	1.47 ± 0.10
3	4.03 ± 0.11	3.28 ± 0.14	2.59 ± 0.14	2.25 ± 0.12
4	61.87 ± 2.13	56.46 ± 2.01	48.76 ± 2.52	46.62 ± 2.33
5	29.36 ± 1.25	30.68 ± 0.94	31.72 ± 1.32	34.48 ± 1.38
6	11.41 ± 0.58	14.30 ± 0.58	16.38 ± 0.68	18.60 ± 0.78
7	5.72 ± 0.45	7.59 ± 0.41	9.50 ± 0.62	9.22 ± 0.45
8	2.39 ± 0.30	3.55 ± 0.32	4.96 ± 0.45	4.92 ± 0.39
9	1.02 ± 0.16	1.78 ± 0.20	2.32 ± 0.29	2.10 ± 0.24
10	0.38 ± 0.12	1.51 ± 0.24	1.88 ± 0.28	2.12 ± 0.29
	$n = 61$	$n = 76$	$n = 50$	$n = 50$

The tables show that the number of particles in the fractions increases throughout from the coarse strainers to the finer ones. In good sets of teeth, the average number in a fraction with strainerholes of 10 mm. in diameter amounts to 0.8, and with holes of 1 mm. in diameter it is 1161. In extremely bad sets of teeth, the average number of particles in the same fractions is 2.7 and 327. (The number of particles in the finest fractions is calculated from standard values for the sedimented volume.) In a comparison of the distribution of the fractions in sets of teeth of varying natures, we find that the number of particles in the

fraction with holes of 5 mm. in diameter keeps fairly constant at something over 30 (29—35 particles). In the fractions in the strainers above No. 5 (coarser fractions), the average number of particles increases as the sets of teeth get worse. The opposite is the case in the finer fractions on strainers underneath No. 5.

Table 48 also gives figures of the average distribution of the fractions for adult women. A comparison with the average distribution of the fractions for adult men shows fairly good agreement of the values for the number of particles and sedimented volume. In extremely good sets of teeth, the average number of particles in a fraction with strainer-holes of 10 mm. in diameter is 0.4, and where the holes are 1 mm. in diameter, 1176. In extremely bad sets of teeth, the average number in the same fractions is 2.1 and 381. In women, too, the number of particles when the diameter of the holes is 5 mm. keeps round about 30 (29—34).

As the test portion is divided into 10 fractions in strainers with holes from 1—10 mm. in diameter, the difference in the size of the particles in neighbouring fractions will be small. Irregular particles, with different diameters in different planes, may therefore to a certain extent just happen to land up in a strainer above or below the one where they actually belong. Special experiments have been made with re-straining of previously strained portions, where the fractions were stained red and blue alternately. After re-straining, the fractions were found containing a slight proportion of particles of the other colour. We have therefore to take into consideration that, statistically speaking, the values for the different fractions should have not inconsiderable standard errors; this can also bee seen from the standard errors, given in the tables, which are calculated from the distribution. However, we also have to reckon with a correlation between the differences between neighbouring strainers, in that, if by chance the number of particles on a certain strainer is small, this is due to their happening either to remain to a particularly large extent in the preceding strainer, or to pass through into the following one. A low value obtained by chance is therefore negatively correlated with the values in surrounding strainers. The impression of an element of uncertainty given by the standard errors in the separate fractions, is therefore somewhat misleading in so far as, if it is possible to reach a uniform expression for the degree of reduction for the entire test portion, the standard error of this value should be considerably smaller than

that of the separate fractions would seem to suggest. It is, further, difficult to reach some idea of the degree of reduction from the varying values for the different fractions. It is necessary in a comparison to keep in mind ten pairs of values. This, as has been said before, is one of the author's motives in working out a mastication coefficient, which has the advantage both of giving a simple expression for the degree of reduction, which considerably facilitates comparison, and also of making it possible to calculate standard errors that correctly express the circumstances, without having laboriously to calculate correlations between the standard errors of the different fractions, and try to make these into one. To make it possible to assess the reduction of the test portion and to compare the effect of mastication in different sets of teeth, mastication coefficients have been calculated from the mean values of the sizes of the fractions. Table 9 gives the values of surface and volume, and also of surface per volume unit, calculated from the mean values for the number of particles and the sedimented volume for adult men and women with extremely good, good, bad and extremely bad sets of teeth.

As has been said before, the table shows the calculated volume to agree fairly well with the known volume of the test portion. The standard deviation amounts to about 10 per cent. With the help of the values for the calculated surface and volume, it is possible to express the results in the following way. The values for the *mastication coefficient* show particles in a test with extremely good sets of teeth to have an average surface of 239 sq. cm., in good ones, 184 sq. cm., in bad ones, 163 sq. cm., and in extremely bad ones, 157 sq. cm. A calculation further shows that, in extremely good sets of teeth, the surface of a test portion is on an average increased by 11 times its original dimensions, in good sets by 8 times, in bad sets by 7 times, and in extremely bad sets by 6.8 times. The results are rather astonishing. The author has at any rate been surprised to find, on the one hand, that chewing the test portion gives such high values for its surface, and, on the other, so small a difference in surface between chewing in good, bad, and extremely bad sets of teeth, while extremely good sets, on the contrary, deviate considerably. The differences computed for 1 c. cm. of the test portion are 5.5 sq. cm. between extremely good and good sets of teeth, 2.1 sq. cm. between

TABLE 49.

Means of individual mastication coefficients in grown-up men and women, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. n = number of persons.
$M \pm \varepsilon(M)$ = mean ± standard error.

Set of teeth	Men		Women	
	n	$M \pm \varepsilon(M)$	n	$M \pm \varepsilon(M)$
Group I: extremely good	63	24.48 ± 0.89	61	24.33 ± 0.61
» II: good	60	18.26 ± 0.47	76	20.22 ± 0.46
» III: bad	51	16.43 ± 0.39	50	17.82 ± 0.53
» IV: extremely bad	55	15.77 ± 0.45	50	17.16 ± 0.37
» I—IV:	229	18.97 ± 0.38	237	20.13 ± 0.31

good and bad sets, and 0.6 sq. cm. between bad and extremely bad sets.

The values for the mastication coefficient that have hitherto been discussed are based on a calculation of the means for fractions with the help of the formulas for volume and surface given in the method. More exact values are obtained, however, if the mastication coefficient for each individual is calculated and the series thus obtained used to compute the means for the different sets. As it is possible when carrying out these calculations to get standard errors for the means, and also figures for the standard deviation and the variation coefficient, the rest of the tables will show exclusively figures calculated on the individual values.

The means for adult men and women, calculated from the individual mastication coefficients, are given in Table 49.

We find good agreement between the values in the table and the mastication coefficient values obtained by a calculating of the means for the fractions (cf. Table 9). But we cannot expect to find them agreeing completely. We have to reckon with chance deviations, as well as systematic deviations due to correlations between volume and surface in separate individuals. As a comparison between the mastication coefficients calculated in different ways shows, these deviations are nevertheless small, and lie within the limits for the standard error.

The figures also show that there are statistically significant differences between the mastication coefficients for the groups of extremely good, good and bad sets of teeth. The difference between the first two for adult men is considerable, amounting to

about a quarter, (6.22 ± 1.01), of the reduction in extremely good sets. Between good and bad sets, the difference drops to a tenth of the portion's surface in good sets, and between bad and extremely bad sets, finally, the difference is negligible, namely 0.66 ± 0.69.

The figures for adult men seem to show that the difference between the sets of teeth becomes smaller, the more defective the set. A comparison between the values for the average mastication coefficients for adult men and women shows excellent agreement in a good set; the coefficients in other groups, on the other hand, show higher values for women than for men throughout. The differences are not statistically significant, however. For adult women, too, we find the differences successively diminishing, the worse the set of teeth becomes, though there is less difference between extremely good and good sets, and more between good and bad sets, than in adult men.

The differences thus seem to imply that, with the class division used by the author, there is a distinct difference in masticatory effectivity between good sets of teeth on the one hand, and more defective sets on the other. This is supported by the fact that the differences between the variously good sets are similar in both men and women. It is impossible to say definitely, on the strength of the figures communicated, that the size of the differences is not conditioned by chance to a certain extent, since their standard errors are great. It may, of course, be chance that the difference between extremely good and good sets of teeth has become particularly large in men, nor does the smaller difference for women argue against this possibility. As will be shown later, the same distribution of the magnitude of the differences is not found in older persons.

As, on account of the means and the standard errors for the coefficients, we cannot definitively assess the successive decrease of the differences between the different sets of teeth, we shall briefly discuss the differences between the classes when divided according to the condition of the teeth, to see whether we can find any pointer here. Statistical viewpoints have decided this division, the class limits being so chosen that approximately the same number of individuals was contained in each. The mean values of the points for pairs of teeth in occlusion in the different sets are given in Chapter 11. The figures in Table 17 show that for men the difference in points between the average for extremely good and good sets is 5.97, between good and bad

sets, 3.45, and between bad and extremely bad sets, 4.17. This shows that there is a relatively smaller difference in the number of points between good and bad sets of teeth, while the differences between the other classes are larger. The class limits used, then, can scarcely explain the successive diminution in the differences between the masticatory effectivity in the different groups. It has not yet been proved beyond dispute, however, that the differences actually do take such a course, and the question must be left open for the time being.

If we now compare the number of points and the mastication coefficient values in the extreme teeth groups, we find, that, for adult men, the number of points sinks from, on an average, 18.54 to 4.95, and for women from 17.87 to 5.06. Thus, the extremely bad set of teeth proves to have 26.7 per cent of the good set's occlusion contacts in men. For women the corresponding figure is 28.3 per cent. The corresponding figure for the occlusal surface is 35.7 per cent for men and 35.2 per cent for women. A corresponding calculation, made on the mastication coefficients for the different sets of teeth in adult men, shows that the extremely bad set has 64.4 per cent of the effect in a good set. For adult women the figure is 70.5 per cent. Thus we can see that there is apparent lack of proportion between the deterioration, on the one hand of the set of teeth, and on the other of the masticatory effectivity.

The successively decreasing masticatory effectivity in defective sets of teeth, which thus is not directly proportionate to their deterioration, might, perhaps, be attributed to a compensatory increase in the number of chews. It has been shown earlier on, however, that this is not the case. The possibility then remains of explaining the decrease by ascribing the relatively good masticatory effect in defective sets of teeth to a certain extent to compensation through more skilful management of the mouthful. Especially might it be suspected that incisors are used more extensively when the grinding teeth are bad.

Mastication effect in old men and women.

It is now of interest to investigate the masticatory effectivity in older men and women. The means for computed individual mastication coefficients are given in Table 50.

A comparison of the figures in the table with those for adult

TABLE 50.

Means of individual mastication coefficients in older men and women, divided into groups with sets of teeth in varying condition. Regarding class limits, see Table 17. n = number of persons.
$M \pm \varepsilon(M)$ = mean ± standard error.

Set of teeth	Men		Women	
	n	$M \pm \varepsilon(M)$	n	$M \pm \varepsilon(M)$
Group I: extremely good	15	36.05 ± 1.79	10	28.70 ± 2.84
» II: good	24	28.40 ± 2.15	17	24.06 ± 1.48
» III: bad	19	26.19 ± 2.39	12	21.44 ± 1.52
» IV: extremely bad	43	20.92 ± 0.80	11	18.48 ± 1.62

men shows the masticatory effectivity for the older men investigated to be remarkably high, and the coefficients in extremely good, good and even bad sets of teeth are higher than the corresponding values for adult men. The differences between older and younger adult men are statistically significant and amount to 11.57 ± 2.00 in extremely good sets of teeth, and 5.15 ± 0.92 in extremely bad ones.

The good masticatory results are not, however, due to the older men chewing a larger number of times. It has earlier on been shown that this is not so (cf. Chapter 12). In trying to explain these good results, an important circumstance may be that the older men investigated had abraded teeth to a very large extent. All abrasion was recorded at the investigation. In so doing, two degrees were differentiated: distinct abrasion, where the cusps were plainly worn down without, however, the tooth surface being completely plane, and pronounced abrasion, when the tooth surface was plane and the height of the tooth somewhat decreased from being worn away. Further details of the distribution for these different classes are not likely to be of interest; the author contents himself with the statement that, with extremely good sets of teeth distinct or pronounced abrasion is found in 100 per cent of the cases, with good sets in 83 per cent, with bad sets in 68 per cent, and with extremely bad sets in 73 per cent. We might now think that the abrasion of the tooth surfaces might explain the good masticatory results, since the abrasion means that such pairs of teeth as exist are ground down to match one another. In comparing the values for the occlusion surface between younger adult and older men (cf. Tables 18 and

26 in Chapter 11), also, we find that the average difference in a good set of teeth is 96.4 ± 27.0 sq. mm. — a considerable difference.

Here, too, we find a lack of agreement between the deterioration of the set of teeth on the one hand, and the decrease in the masticatory effectivity on the other. A calculation shows that the extremely bad set of teeth has 77.5 per cent of the extremely good set's lower occlusion contacts, while its mastication coefficient, on the other hand, is 42 per cent lower than that of the extremely good set. The per cent figures tally fairly well with the figures for adult men and women, a fact which certainly goes towards endorsing the results.

Table 50 shows, further, that in a comparison between the figures for older and younger adult women, the former show higher mastication coefficients for the different sets of teeth. The differences are, however, small, and not statistically significant. Between older and younger adult women, the difference in extremely good sets of teeth is 4.37 ± 2.91. We also find that, for older women, there is no statistically significant difference between the different groups. The greatest difference is between extremely good and good ones (4.61 ± 3.20), and this is not statistically significant. The number of older women investigated is small, however, and the standard errors for the different groups of teeth are consequently great. On account of this the size of the difference is very subject to chance, which means that the different groups can lead us to no definitive conclusions. All the same, the difference between an extremely good set of teeth and an extremely bad one is statistically significant, and amounts to 10.22 ± 3.27.

Mastication effect in children.

It now remains to investigate the masticatory effectivity in children. Table 51 gives the means for the calculated individual mastication coefficient for 7-year-old and 13-year-old girls and boys. The differences between the different teeth groups are, as in adult men and women, statistically significant.

The values for the mastication coefficient for 13-year-old girls and boys are higher than for 7-year-olds and adults. The differences are small, however, and the difference in good sets of

TABLE 51.

Means of individual mastication coefficients in seven-year-old and thirteen-year-old children, divided into groups with sets of teeth in varying condition. Regarding class limits, see Tables 32 and 36. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error.

Set of teeth	n	$M \pm \varepsilon(M)$
Seven-year-old children		
Group I: extremely good	8	22.25
» II: good	29	20.77 ± 0.77
» III: bad	35	16.59 ± 0.50
» IV: extremely bad	28	15.13 ± 0.45
Thirteen-year-old children		
Group I a: perfect	18	26.28 ± 1.42
» I b: very good	36	25.05 ± 0.80
» II: good	37	22.15 ± 0.63
III: bad	9	19.59

teeth not statistically significant. The difference between 13-year-olds and 7-year-olds is 1.38 ± 0.99.

A calculation of the difference in number of contacts between extremely good and extremely bad sets of teeth shows a deterioration of the set by 65.2 per cent for 7-year-olds, and by 49.7 per cent for 13-year-olds. A calculation of the difference in the masticatory effectivity from extremely good to bad sets yields 32.9 for 7-year-olds, and 25.5 for the others.

We find in children, as in the groups investigated earlier, a difference between good and bad sets of teeth as regards the mastication coefficient, which, in relation to the difference in the set in respect of grinder contacts, is comparatively small.

When comparing the mastication coefficient for children with the one for adults it must be remembered that for children a smaller test portion has been used than for adults. In 15 adults, special tests have been made. Each subject has been tested with the larger (10.6 c. cm.) and the smaller (7.4 c. cm.) test portion. When this first was done the persons were told to chew 60 times. The mean of the differences between the mastication coefficients was found to be 3.04 ± 0.52. In other words, there was a significant difference, the mastication coefficient being higher for the smaller test portion. It should be remembered that, when the test portion

is larger, the number of chews increases. Possibly, this increase causes the difference to disappear. Therefore, the same tests has been made on the 15 persons, when they were allowed to chew until they felt ready to swallow. In this case the mean of the differences was 0.39 ± 0.55. The small increase in the mastication coefficient was not significant, and in fact, the agreement may be said to be good. Of course a small significant difference may be found in a larger material, but, in any case for the test used, the difference because of the size of the test portions cannot be very important. Therefore, we may compare the mastication coefficients for children and adults.

The figures show that the values for the mastication coefficient for 7-year-old children agree fairly well with those for younger adult women and men alike. Only for extremely bad sets of teeth a significant difference was found when comparing with women. (Difference 2.03 ± 0.58.) In regard to 13-year-old children a significant difference was found for good sets of teeth in comparison with men; the difference was 3.89 ± 0.79. In comparison with women no significant difference was found. Anyhow there seem to be no very important differences between children and adults.

Summing up, then, it may be said that an investigation of the masticatory effectivity with the help of the mastication coefficient has showed clear average differences between adult men and women in groups with varying sets of teeth. Similar differences have also been found in older men and women, and in children. Nevertheless, the difference in the masticatory effectivity seems throughout to be less than might be expected in the light of the different nature of the sets and the total occlusal surface. This is not due to the fact that defects in the sets are compensated by an increased number of chews, and the most plausible assumption is, that a certain compensation is achieved by a more skilful manoeuvring of the mouthful to the contacts that are left, and that incisors are used to a certain extent. It must be remembered that even in extremely bad sets of teeth the incisors are still in a comparatively good condition. (Possibly, the chewing is done harder, too.) It is furthermore striking that children and adults, whose sets of teeth have the same character, have about the same average masticatory effectivity, whereas old people in the same classes have a greater effectivity, and thus higher mastication coefficients. (It has been possible to show

this for older men. The material for older women has been too small to give statistically significant differences.) The most plausible explanation is that, on account of abrasion, the older people often have an occlusal surface which is more effective for the test material used.

Chapter 14.

The variation in reduction of test portions, and its causes.

To throw further light on the masticatory effectivity in different sets of teeth, we shall now investigate the variation. Table 52 gives the figures for standard deviation and variation coefficients computed from the mastication coefficients for different teeth groups among children, adults, and older persons.

If, as was done earlier on in the discussion of the average mastication coefficient, we now begin by investigating the variation for adults, we find it getting less from extremely good to extremely bad sets of teeth in both younger adult men and women. The differences between the extreme groups are statistically significant for both sexes. The figures in the table show that, for women, the difference for the standard deviation values between neighbouring groups is not statistically significant, apart from that between good and extremely bad sets of teeth (difference 1.40 ± 0.42). For men, we find a statistically significant difference between extremely good and good sets of teeth (difference 3.39 ± 0.71), but not in other groups.

Given that the range of variation for the mastication coefficient slightly decreases as the set of teeth gets worse, we might expect the variation coefficient — i. e. the standard deviation expressed in per cent of the appertaining mean — to keep more constant, since the mean for the mastication coefficients also decreases. There is, as a matter of fact, a tendency in this direction. All the same, there is a statistically significant difference in men between group I and group III, and a statistically probable one between groups I and II; otherwise, however, there are no certain differences between the variation coefficients in adult men and women. The two figure series for men and women might possibly suggest a tendency towards a falling coefficient, which would imply that the range of variation decreased relatively more than the means for the mastication coefficients; a lar-

TABLE 52.

Standard deviation and variation coefficient of the mastication coefficient. Grown-up men and women, older men and women, and seven-year-old and thirteen-year-old children, divided into groups with sets of teeth in different condition. n = number of persons. $\sigma \pm \varepsilon(\sigma)$ = standard deviation $\pm$ standard error. $V \pm \varepsilon(V)$ = variation coefficient $\pm$ standard error.

Set of teeth	n	$\sigma \pm \varepsilon(\sigma)$	$V \pm \varepsilon(V)$
Grown-up men			
Group I: extremely good	63	7.04 ± 0.63	28.8 ± 2.8
» II: good	60	3.65 ± 0.33	20.0 ± 1.9
» III: bad	51	2.79 ± 0.28	16.9 ± 1.7
» IV: extremely bad	55	3.31 ± 0.32	21.0 ± 2.1
Groups I—IV:	229	5.82 ± 0.27	30.7 ± 1.6
Grown-up women			
Group I: extremely good	61	4.79 ± 0.43	19.7 ± 1.9
» II: good	76	4.02 ± 0.33	19.9 ± 1.7
» III: bad	50	3.74 ± 0.37	21.0 ± 2.2
» IV: extremely bad	50	2.62 ± 0.26	15.3 ± 1.6
Groups I—IV:	237	4.80 ± 0.22	23.8 ± 1.2
Older men			
Group I: extremely good	15	6.94 ± 1.27	19.2 ± 3.6
» II: good	24	10.52 ± 1.52	37.0 ± 6.0
» III: bad	19	10.43 ± 1.69	39.8 ± 7.4
» IV: extremely bad	43	5.26 ± 0.57	25.2 ± 2.9
Groups I—IV:	101	9.49 ± 0.67	36.6 ± 2.9
Older women			
Group I: extremely good	10	9.00 ± 2.01	31.3 ± 7.7
» II: good	17	6.10 ± 1.05	25.3 ± 4.6
» III: bad	12	5.25 ± 1.07	24.5 ± 5.3
» IV: extremely bad	11	5.37 ± 1.14	29.1 ± 6.7
Groups I—IV:	50	7.09 ± 0.71	30.6 ± 3.3
Seven-year-old children			
Group I: extremely good	8	—	—
» II: good	29	4.13 ± 0.54	19.9 ± 2.7
» III: bad	35	2.97 ± 0.35	17.9 ± 2.2
» IV: extremely bad	28	2.38 ± 0.32	15.7 ± 2.2
Groups I—IV:	100	5.06 ± 0.36	21.3 ± 1.6
Thirteen-year-old children			
Group I a: perfect	18	6.03 ± 1.01	22.9 ± 4.0
» I b: very good	36	4.82 ± 0.57	19.2 ± 2.4
» II: good	37	3.86 ± 0.45	17.4 ± 2.1
» III: bad	9	—	—
Groups I—III:	100	4.24 ± 0.30	23.7 ± 1.8

ger material is needed before such a tendency can be established, however.

In the total material the variation coefficient for adult men is 30.7 ± 1.6 per cent, and for adult women 23.8 ± 1.2 per cent. For older men and women the coefficient is about 6 per cent higher than for the younger groups, and for children about the same as for adult women. Our next concern is to get some idea of why we obtain such varying values. Obviously, a fundamental reason must be that people chew different numbers of times. It has been shown earlier on that there is great variability in this respect; people chew their food for different lengths of time, and with different degrees of conscientiousness. Some people are content with a few chews, others take many. There is, further, a variability in so far as one person does not always chew in exactly the same way; but, as has already been shown, this variability is not very great.

Another obvious reason for variation is that the sets of teeth in a group vary somewhat in character. This tendency has been illustrated in more detail previously (Chapter 11). We have not been able to compare more homogeneous sets, as the material in the different classes would then have been very small.

A minor source of variability is that the method used to reach the mastication coefficient by means of straining is not absolutely exact, but has a standard error. The variation due to error of measurement is very slight, however. It is, of course, possible to discuss a number of other factors that certainly have some small importance, e. g. there is no doubt that a varying degree of abrasion plays a part, above all in older persons. Other examples are different-sized teeth in different individuals, which give a varyingly effective occlusal surface and, further, a more, or less, satisfactory occlusion. Of course anatomical differences of various kinds must be of importance, and especially it must be remembered that people with malocclusion are included in the material. Later on we shall be paying particular attention to this group, but we will say here and now that individuals with pronounced malocclusion are far too few to play any very great part. Finally, there is the possibility of varying degrees of skill, in particular on the part of persons with defective sets of teeth, in manoeuvring the mouthful to those places with the best mastication effect; we can also reckon with some people chewing harder than others.

If we look at the figures showing the standard deviation for older men, we find small but significant differences between extremely bad sets of teeth on the one hand, and good and bad sets on the other. The group with extremely good sets of teeth comprises few individuals only, so that no difference between it and other groups can be established. The material for older men is, on the whole, not as large as for adult men, and we are therefore not surprised at being unable to make out a definite trend in the figures. The material for older women is still smaller, so that it is natural that we should not find significant differences or definite tendencies here, either. If we look at the variation coefficients, we find no significant differences anywhere.

A comparison with adult men shows greater range of variation in older men, however, and greater variation coefficients. Nevertheless, differences can be proved only in certain groups, namely those for old men with bad and extremely bad sets of teeth. For good sets, the difference is probable. It is true that, for the old women, we get throughout higher figures than for the younger ones; but the groups are too small to give significant differences. As has already been mentioned, the total groups have significant differences between the age groups for both men and women (3.67 ± 0.72 for men, 2.29 ± 0.74 for women).

If we then look at the children, we find no statistically significant differences between the groups for the 13-year-olds. The figures do have a tendency to a diminishing range of variation, which also seems reflected in the variation coefficients, without, however, the difference being significant here. In the 7-year-olds, we find practically significant differences between good and extremely bad sets of teeth (difference 1.75 ± 0.63), and a shift in the variation coefficients towards lower values in more defective sets, which, however, is not statistically significant but may conceivably have arisen at random.

If, finally, we compare the variability in children with that in adults, we find no striking difference. The difference between 13-year-olds and adult men is nevertheless significant (1.58 ± 0.40).

Summing up with regard to the variability in masticatory effectivity, we may say that this is by no means inconsiderable in groups with more or less similar sets of teeth, and that the variation coefficient keeps, on the whole, between 20 and 30 per cent, being apparently somewhat larger in good sets, and somewhat lower in bad ones.

TABLE 53.

Mastication coefficients in tests with 20 chews and 40 chews respectively. Grown-up men and women, divided into groups with sets of teeth in different condition. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation.

Set of teeth	n	20 chews		40 chews	
		$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ
Men					
Group I: extremely good	63	16.30 ± 0.52	4.17	20.28 ± 0.45	3.55
» II: good	60	14.01 ± 0.31	2.38	17.33 ± 0.41	3.14
» III: bad	51	12.65 ± 0.23	1.66	14.85 ± 0.27	1.95
» IV: extremely bad	55	12.08 ± 0.21	1.56	14.45 ± 0.31	2.27
Women					
Group I: extremely good	61	17.08 ± 0.31	2.42	22.25 ± 0.47	3.67
» II: good	76	14.79 ± 0.28	2.40	18.64 ± 0.34	2.95
» III: bad	50	13.72 ± 0.28	1.96	16.56 ± 0.36	2.57
» IV: extremely bad	50	13.20 ± 0.27	1.93	15.43 ± 0.30	2.11

Mastication coefficient and number of chews.

To see what significance there is in the fact that a person does not always chew the same number of times, a comparison has been made between persons who have chewed exactly 20 and 40 times respectively. First of all, we give in Table 53 the mean values for the mastication coefficients in such comparisons between adult men and women.

The figures in the table show that, as expected, the mastication coefficient in both 20 and 40 chews gets less as the set of teeth gets worse. (The differences between extremely good and good sets, and between good and bad sets, are significant both for men and for women, but for neither is this the case in regard to the difference between bad and extremely bad sets.) A comparison of the mastication effect between men and women shows that women possibly have higher values for the mastication coefficient, both in 20 and in 40 chews, although the differences are not significant, except for the groups of good sets and bad sets with 40 chews. Finally, the table shows that the variability decreases from good to bad sets of teeth to possibly a higher degree in men than in women.

TABLE 54.

Means of differences between mastication coefficients in tests with 20 chews and 40 chews respectively. Grown-up men and women, divided into groups with sets of teeth in different condition. n = number of persons. + means that the mastication coefficient in tests with 40 chews is greater than the mastication coefficient in tests with 20 chews.

Set of teeth	Men		Women	
	n	$M \pm \varepsilon(M)$	n	$M \pm \varepsilon(M)$
Group I: extremely good	63	$+ 3.98 \pm 0.54$	61	$+ 5.17 \pm 0.27$
» II: good	60	$+ 3.32 \pm 0.31$	76	$+ 3.86 \pm 0.21$
» III: bad	51	$+ 2.20 \pm 0.23$	50	$+ 2.84 \pm 0.23$
» IV: extremely bad	55	$+ 2.38 \pm 0.24$	50	$+ 2.23 \pm 0.22$

Meanwhile, it is of special interest that the masticatory effect considerably increases when the number of chews is raised from 20 to 40. The increase seems to be as large for men as for women. To investigate more closely the difference in masticatory effect between 20 and 40 chews, figures are given in Table 54 of differences calculated on the individual values for mastication coefficients (thus, they have not been obtained from the mastication coefficient means in the previous table).

We might now expect to get something approaching double the masticatory effect in the same teeth classes, on the increase of the number of chews from 20 to 40. Quite apart from the number of chews and the nature of the set of teeth (which in this case is not, of course, of any importance, as the comparison of the effect concerns the same individuals), other factors, already discussed, also influence the masticatory effect. It is therefore interesting to investigate, firstly, how great the increase is in the same teeth classes, and, secondly, whether the increase takes place to the same degree in the various sets of teeth. If we begin by comparing the differences in effect in variously good sets of teeth, we see from the figures in the table that the difference between the mastication coefficients in 40 and 20 chews grows less from extremely good to extremely bad sets. The differences between the classes are not significant throughout, however. (For men, there are probable differences between groups I and III, I and IV, and II and III. Women show significant differences between all groups except III and IV.) To gauge the increase of the mastication effect when the number of chews rises from 20 to 40, the

TABLE 55.

Mastication coefficients for grown-up men and women with extremely good or extremely bad sets of teeth, distributed with regard to number of chews. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error.

Number of chews	Men		Women	
	n	$M \pm \varepsilon(M)$	n	$M \pm \varepsilon(M)$
Extremely good set of teeth				
Below the 1st quartile	16	19.9 ± 1.1	16	21.8 ± 1.3
Between the 1st quartile and the median	16	22.2 ± 1.3	15	24.0 ± 1.3
Between the median and the 3rd quartile	16	26.1 ± 1.4	15	25.5 ± 1.3
Above the 3rd quartile	15	30.1 ± 2.2	15	26.1 ± 0.9
Extremely bad set of teeth				
Below the 1st quartile	15	13.92 ± 0.50	13	14.88 ± 0.33
Between the 1st quartile and the median	12	16.16 ± 1.30	12	16.17 ± 0.46
Between the median and the 3rd quartile	15	16.24 ± 0.80	12	18.10 ± 0.63
Above the 3rd quartile	13	16.99 ± 0.85	13	19.51 ± 0.73

difference between the mastication coefficients for both 20 and 40 chews has been reckoned in per cent of the mastication coefficient value at 20 chews. We then find that for men, the increase in extremely good and good sets of teeth amounts to about 24 per cent, and in bad and extremely bad sets to about 20 per cent. The corresponding figures for women are rather more than 30 per cent, and not quite 17 per cent, respectively.

It would have been interesting to investigate the increase in masticatory effect with a higher number of chews, e. g. 80, and compare this effect with the values for the mastication coefficient in 20 and 40 chews. Such tests have not been made, since it was thought that yet another test would prove rather too much for the subjects. All the same, a comparison can be made by grouping the material according to number of chews into 4 equal groups, and comparing the masticatory effect in low and high numbers of chews.

Table 55 gives the means for mastication coefficients in extremely good and extremely bad sets of teeth for adult men and women. The material is grouped within limits, set with the help of medians and quartiles, for the number of chews. An increase is found which is admittedly not significant from the one group to the next, but which nevertheless persists throughout. If those with a high number of chews are compared with the

group showing a low number of chews, we find significant differences for both men and women, and in extremely good and bad sets of teeth alike. (In extremely good sets of teeth in women, however, the difference is only probable.) If the difference is, as before, expressed in per cent of the lower value for the mastication coefficient, we get more comparable figures, which seem larger for the men than for the women, in so far as men with extremely good sets of teeth have the highest per cent figure for the increase (51 ± 12 per cent), and women with extremely good sets the lowest one (19.7 ± 7.3 per cent). The inequality in the differences (which is not significant) is probably for the most part conditioned by chance, however, which, of course, transpires from the standard errors. In extremely bad sets of teeth, the corresponding figures for men are 22.1 ± 7.1 per cent, and for women 31.1 ± 4.1 per cent.

Of further interest now is to try and get an idea of the proportion of the changes in mastication coefficients, due to a changed number of chews. We must then get an approximate idea of the average number of chews characterizing these groups. By means of a special collocation, the mean number of chews has been calculated in each group. Thus, for men with extremely good sets of teeth, the average number for the first group is 40, for the second group 55, for the third group 74, and for the fourth group 107. Average coefficients corresponding to these values are 20, 22, 26, and 30 respectively. As has previously been shown, a mastication coefficient of 16 corresponds to 20 chews. This signifies that when the number of chews increases about 5 times, the mastication coefficient is only increased about 2 times. If we plot mastication coefficients against number of chews on a graph, we find that the changes in the mastication coefficient in relation to the number of chews follow a more or less straight line. The same investigation has been made on women with extremely good sets of teeth, and also for men and women with extremely bad sets. We find differences, which, however, probably lie within the limits for the standard error, and which imply a proportionately fainter increase of the mastication coefficient values in relation to the number of chews. All the same, the increase still follows a more or less straight line. Further, it is of special interest that, as pointed out above, the increase in the mastication coefficient is not proportionate to the increase in the number of chews.

To throw further light on the connection between masticatory

TABLE 56.

Correlation between mastication coefficients and number of chews. Grown-up men and women divided into groups with sets of teeth in varying condition. n = number of persons. $r \pm \varepsilon(r)$ = correlation coefficient $\pm$ standard error.

Set of teeth	Men		Women	
	n	$r \pm \varepsilon(r)$	n	$r \pm \varepsilon(r)$
Group I: extremely good	63	$+0.667 \pm 0.070$	61	$+0.330 \pm 0.114$
» II: good	60	$+0.588 \pm 0.084$	76	$+0.527 \pm 0.083$
» III: bad	51	$+0.550 \pm 0.098$	50	$+0.518 \pm 0.103$
» IV: extremely bad	55	$+0.294 \pm 0.122$	50	$+0.749 \pm 0.062$
Groups I—IV:	229	$+0.429 \pm 0.054$	237	$+0.346 \pm 0.057$

effectivity and the number of chews, correlations between the number of chews and the mastication coefficient have been calculated for adult men and women. Seeing that, as has been shown above, there is a practically straight-line connection, Bravais-Pearson's correlation coefficient has been used at the calculations. Table 56 gives the values for correlation coefficients for adult men and women with varying sets of teeth. From the figures in the table we can see that there is, both for men and for women, a definite correlation between the masticatory effectivity and the number of chews: for men $r = +0.13 \pm 0.05$, and for women $r = +0.35 \pm 0.06$. For the former, the correlation drops from 0.67 to 0.29, reckoning from extremely good to extremely bad sets of teeth, and for the latter, from $+0.75$ to $+0.33$, reckoning from extremely bad to extremely good sets of teeth. The differences between neighbouring groups are not statistically significant, however, either for men or for women. On the other hand, the extreme groups show a significant difference for women, and a probable one for the men. If we compare the correlation between the two sexes, we find the values agreeing in good and bad sets of teeth. In the extreme groups, on the other hand, we find the correlation for women about half that for the men in extremely good sets of teeth, and about 2.5 times as large in extremely bad sets. The difference in the former case is probable ($+0.34 \pm 0.13$), and in the latter case, significant ($+0.45 \pm 0.14$).

Having now found a distinct correlation between mastication coefficient and number of chews, the correlation has been cal-

TABLE 57.

Correlation between number of chews in two successive tests. Grown-up men and women with extremely good or extremely bad sets of teeth. n = number of persons. $r \pm \varepsilon(r)$ = correlation coefficient ± standard error.

Set of teeth	Men		Women	
	n	$r \pm \varepsilon(r)$	n	$r \pm \varepsilon(r)$
Group I: extremely good	63	$+0.928 \pm 0.017$	61	$+0.940 \pm 0.015$
» IV: extremely bad	55	$+0.734 \pm 0.062$	50	$+0.914 \pm 0.028$

culated for men and women in the extreme groups (extremely good and extremely bad sets of teeth) between the number of chews in two consecutive tests, where the portion was chewed until it felt ready to swallow. Figures are given in Table 57.

The figures in the table show the correlation between the number of chews in consecutive tests to be very strong. Here, there is excellent agreement between men and women with extremely good sets of teeth; extremely bad sets, however, show a probable difference between men and women. The strong correlation tallies with the fact, shown earlier on, that the variation in the number of chews is comparatively small between two tests coming one after the other.

Taking this fact into account, it has been interesting to investigate how strong a correlation in mastication effect is to be found in two consecutive tests. Figures are given in Table 58.

The figures show that, as expected, the correlation between mastication coefficients in extremely good and extremely bad sets of teeth is extremely high, for both men ($r = 0.87 \pm 0.03$) and women ($r = 0.71 \pm 0.06$). We also find, as we did from the values in Table 56, that the correlation seems, for men, to be higher in extremely good sets of teeth than in extremely bad ones, and for women, vice versa, though the differences are not significant, all the same. We also find that the correlation coefficient for men with extremely good teeth agrees with the value for women with extremely bad sets, and that the correlation coefficient for women with extremely good sets of teeth agrees with the value for men with extremely bad ones.

The high correlation coefficient values, which we have now found in calculating the correlation between the number of chews

TABLE 58.

Correlation between mastication coefficients in two successive tests. Grown-up men and women with extremely good or extremely bad sets of teeth. n = number of persons. $r \pm \varepsilon(r)$ = correlation coefficient $\pm$ standard error.

Set of teeth	Men		Women	
	n	$r \pm \varepsilon(r)$	n	$r \pm \varepsilon(r)$
Group I: extremely good	63	$+0.873 \pm 0.030$	61	$+0.716 \pm 0.063$
» IV: extremely bad	54 [1]	$+0.704 \pm 0.069$	50	$+0.850 \pm 0.039$

and the mastication coefficient, show that the variation in the number of chews is a fundamental cause of the variation in the mastication effectivity.

Mastication coefficient and the condition of the teeth.

The variation in the masticatory effectivity is also connected with variation in the sets of teeth, which latter can now be numerically evaluated in two different ways with the methods worked out by the author. The correlation can be calculated between the point values of the teeth or the occlusion surface on the one side (as expressing the character of the set of teeth), and the computed mastication coefficients, on the other. The correlation coefficients thus obtained will then give an idea of the connection between the nature of the set of teeth and the masticatory effectivity.

Correlation calculations are in the first place made between the masticatory effectivity and the number of occlusion contacts. They show that there is a strong correlation between the mastication coefficient and the number of contacts. The values for the correlation coefficient show good agreement between men and women, amounting for the former to 0.572 ± 0.044, and for the latter to 0.566 ± 0.044. Corresponding calculations have also been made for men and women with regard to the connection between the mastication coefficient and the occlusion surface. This calculation, too, shows a strong correlation, with a coefficient of 0.617 ± 0.041 for men, and of 0.491 ± 0.050 for women. There are no significant

[1] Information is lacking for 1 case of 55.

differences between the correlation coefficients obtained from the calculated points, and those obtained from the occlusion surface. The investigation supports the notion that the nature of the set of teeth is quite as important to the masticatory effectivity as is the number of chews.

It has been mentioned earlier on that the investigated material of adult men and women contain isolated cases of malocclusion. All cases that came for investigation have been included, in order to get a representative material. The cases with malocclusion have been registered, so that it is possible to investigate their masticatory effectivity. For a rough orientation, the author has confined himself to tabulating the extent to which dental anomalies occur above and below the median for the mastication coefficients in the different groups. Of the total material of 466 adult men and women, we find 103 individuals with anomalies, i. e. 22.1 ± 1.9 per cent. If the anomalies had been of no importance, we should have expected 50.0 ± 4.9 to lie above the median for the respective groups, and the same number to lie below. The figures obtained are 39.8 per cent above the median, and 60.2 per cent below. There is no significant deviation from what we should expect from chance. It is possible that significant differences might be obtained from a larger material. All the same, the figures we get do not indicate that the cases of anomaly displayed a more divergent mastication effect than other individuals, and their values lie, for the rest, well within those of the normal range of variation.

The range of variation.

Table 59 shows the distribution in both sexes for the whole of the lumped together material. Here, a class division of 0.5 σ round the means has been used for men and women respectively. The distribution is somewhat skew, in so far as high extreme values appear more extensively than low extreme values. The distribution appears to go from 2 σ below the mean (for men, 19.01 ± 0.39 sq. cm./c. cm., and for women, 20.23 ± 0.32 sq. cm./c. cm.), up to 4 σ above the mean (cf. Table 59). It is, however, worthy of note that one man had a mastication coefficient that deviated more than 5 σ from the mean: it was 49.6 sq. cm./c. cm. This person was, on principle, an eater of raw vegetables, and chewed extremely thoroughly, reaching 142 times. Thus he exhibited an

TABLE 59.

Distribution of mastication coefficients and occlusion surfaces. Total material of grown-up men and women. As class interval has been used for men: $0.5\sigma = 2.9$ sq. cm./c. cm. and $= 62.9$ sq. mm.; for women: $0.5\sigma = 2.4$ sq. cm./c. cm. and $= 55.7$ sq. mm. M = mean.

Class intervals	Men				Women			
	Mastication coefficient		Occlusion surface		Mastication coefficient		Occlusion surface	
	Number	%	Number	%	Number	%	Number	%
$4\ \sigma$	—	—	—	—	1	0.4	—	—
3.5σ	3	1.3	1	0.4	—	—	—	
$3\ \sigma$	2	0.9	2	0.9	4	1.7	1	0.4
2.5σ	3	1.3	2	0.9	4	1.7	3	1.3
$2\ \sigma$	10	4.4	10	4.4	9	3.8	11	4.8
1.5σ	11	4.8	22	9.7	20	8.4	24	10.4
$1\ \sigma$	27	11.8	36	15.9	28	11.8	36	15.6
$+ 0.5\sigma$	34	14.8	41	18.1	45	19.0	41	17.7
M								
$- 0.5\sigma$	54	23.7	35	15.4	40	16.9	42	18.1
$1\ \sigma$	63	27.5	43	18.9	47	19.8	32	13.9
1.5σ	20	8.7	19	8.4	35	14.8	23	10.0
$2\ \sigma$	1	0.4	13	5.7	4	1.7	13	5.6
2.5σ	—	—	3	1.3	—	—	5	2.2
Total	229 [1]	100.0	227 [2]	100.0	237	100.0	231 [3]	100.0

extreme value as regards number of chews, also. He belonged, incidentally, to the class with extremely good teeth.

It has been mentioned earlier that the number of chews, too, shows a skew distribution, extending from 2 σ inclusive, up to almost 3.5 σ round a mean of 67.8 chews for men, and 58.5 for women (cf. Table 46). It is interesting to investigate the distribution with regard to occlusion surface, also. Figures for this are included in Table 59, where it is seen that the occlusion surface varies from 2.5 σ below the mean up to 3—3.5 σ above the mean, which is 299.7 ± 8.3 sq. mm. for men, and 295.1 ± 7.3 sq. mm. for women. Here, too, then we have a skew distribution. Actually, the skew distribution of the mastication effect is probably connected with the asymmetry which is found both for the number of chews and the occlusion surface.

[1] With regard to mastication coefficient there is one of 229 individuals between $+5\sigma$ and $+5.5\sigma$, corresponding to 0.4 per cent of the material.

[2] Information is lacking for 2 of 229 persons.

[3] » » » » 6 of 237 »

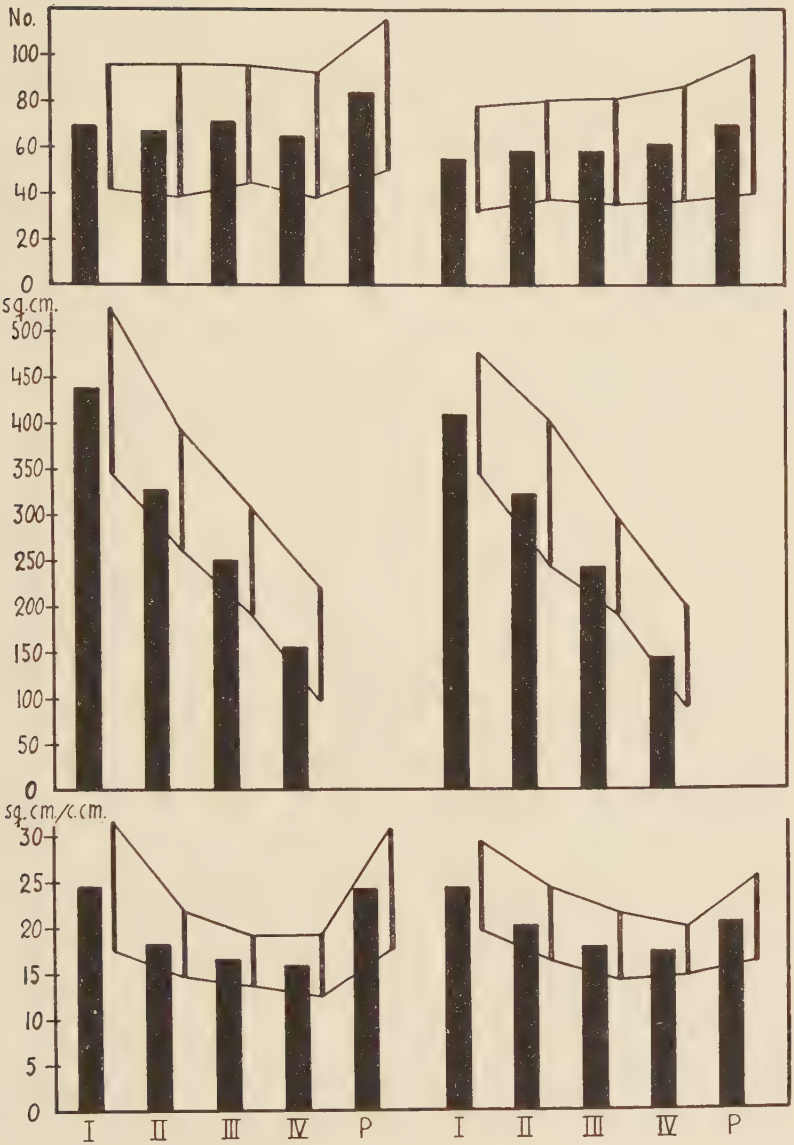

Fig. 7. At the top, the number of chews, on the second line, the occlusion surface, at the bottom, mastication coefficients, for men (to the left) and women (to the right) with different sets of teeth (groups I—IV) and with prostheses (P). The black columns give the means and the vertical lines the standard deviation.

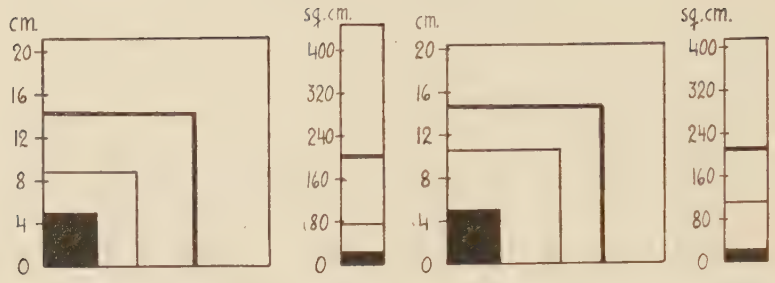

Fig. 8. Diagram showing the surface of the test after chewing, in comparison with the surface of the test portion. To the left men, to the right women. For both are given two diagrams, one with the surface expressed in squares and another with the surface expressed in the height of a column. The surface of the test portion is black, the mean after chewing is given in thick lines, the limits for the range of variation in thin lines.

Finally, Figure 7 shows both mean and range of variation for the number of chews, the occlusion surface, and the mastication coefficient, for adult men and women. We can see from the diagram that, as has been shown earlier on, the average number of chews and its variability remain constant when the set of teeth gets worse; we also see that the average occlusion surface decreases strongly and in a straight line in the different classes. The differences towards a smaller standard deviation which occur are not of importance. Then Figure 7 shows that the masticatory effectivity diminishes — though much less markedly than the occlusion surface — for the different classes, at the same time as the standard deviation also diminishes somewhat. The diagram is intended to summarize the results obtained earlier.

To elucidate the mastication coefficient and its range of variation a survey is given in Figure 8 of the average surface enlargement found in adult men and women in relation to the original surface of the test portion. The diagram also gives the limits for the range of variation. The figure refers to the lumped together material of men and women with sets of teeth of varying types.

Individual and interindividual variation.

To get a more differentiated idea of the general variation in the mastication effect, we now divide up the variation for adult men and women into the individual variation which conditions

TABLE 60.

Total standard deviation of the mastication coefficient (σ_t) for men and women, divided into groups with different sets of teeth, individual standard deviation (σ_i) and calculated inter-individual standard deviation (σ_p) for the corresponding groups. n = number of persons.

Set of teeth	n	σ_t	σ_i	σ_i in % of σ_t	σ_p	σ_p in % of σ_t
			Men			
Group I	63	7.04	2.54	36.1	6.57	93.3
» II	60	3.65	1.82	49.9	3.16	86.6
» III	51	2.79	1.46	52.3	2.30	82.4
» IV	55	3.31	1.68	50.8	2.85	86.1
Groups I—IV	229	5.82	1.96	33.7	5.48	94.2
			Women			
Group I	61	4.79	2.54	53.0	4.06	84.8
» II	76	4.02	1.68	41.8	3.65	90.8
» III	50	3.74	1.05	28.1	3.59	96.0
» IV	50	2.62	1.01	38.5	2.42	92.4
Groups I—IV	237	4.80	1.74	36.3	4.47	93.1

differences between repeated tests of one and the same person, and the variation which is found between different persons after the individual variability has been subtracted from the total one (cf. Chapter 12). Figures obtained in this way are given in Table 60. The table gives, then, for adult men and women with different sets of teeth, firstly the observed total variability, σ_t, secondly the individual variability, σ_i, thirdly the calculated interindividual variability, σ_p. We have discussed before the variability for different teeth groups, and shown that it drops from extremely good to extremely bad sets both in men and women. The individual variability shows a similar drop, as does also the interindividual variability. This means that if we calculate the respective sizes of the individual variability and the interindividual variability in per cent of the total variability, we get figures that remain fairly constant. The variations that do occur are probably, at any rate in large measure, due to chance. On the whole, the interindividual variability is 90 per cent of the total, and the individual variability 40—50 per cent of the total. The figures do not, of course, add up to 100 per cent.

If, lastly, we look at the lumped together material, we find the interindividual variability taking the rather larger share in the total variability of not quite 95 per cent, while the individual variability is about 35 per cent. In this material, the interindividual variability will, of course, form a larger proportion, as the lumping together of different classes of teeth is a further reason for variability in the form of an increased variation in the occlusion surface.

The fact that we get a varying result — i. e. an individual variability — when one person carries out repeated tests, is due to his chewing a different number of times, but it is certainly also due to the chews being, in other ways too, carried out differently. In consideration of the fact that the chewing habits, as has been shown earlier on, are comparatively constant, it is probable that these other factors play a not unimportant part.

The far greater variability in respect of differences between individuals is conditioned both by a great variability in the number of chews, and also by a greater variability in the occlusal surface. In the light of the correlation coefficients computed earlier, we have most reason to suppose that these two factors are of about equal importance. But here, too, we have to reckon with different degrees of skill in the management of the mouthful, the fact that some people chew harder than others, and dissimilarities in the anatomical structure of the set of teeth, which cannot be measured by the occlusion surface with the method used here.

Chapter 15.

Mastication effect with full prosthesis.

In a population, there are, of course, a not inconsiderable number of persons, mainly the rather older ones, who have no teeth of their own, and who must resort for chewing food to artificial teeth. It is of interest from a practical viewpoint to try and get an idea of the mastication effect in chewing with full prosthesis, and it is also interesting to see how effective the masticatory powers in persons with full prostheses are, compared with persons who have their own teeth.

In describing the material in Chapter 8, we gave figures in Table 13 of the age and sex of the investigated persons with full prostheses. We will only mention here that these persons consisted of 50 men and 50 women between about 40 and 80 years of age, most of them between 55 and 70. The prostheses were grouped into three groups: extremely good, good, and bad. The motives for grouping were subjective, building on an estimation of the stability and suction powers of the dentures, and also on the occlusion of the rows of teeth. When grouping, the author confirmed his judgments by asking the wearers how good they themselves thought their dentures were, for chewing. As a rule, their assessements seem to have agreed with his.

The first concern here was to get an idea of the masticatory effectivity in full prostheses of a fairly ordinary nature, where their owners had become used to them. In other words, the investigation concerns full prostheses that have been in use some time. The author's general impression of the prostheses investigated was that they were not of a very superior order, but not (with a few exceptions) below standard, either. It may be mentioned that a number of them were made at dental clinics, treating those who cannot afford to pay.

It is a generally accepted view that it is difficult to chew with full dentures. A reason for this given in the literature, for example, is that one cannot chew so hard as with one's own

teeth, so that is is difficult to crush the food between the tooth surface. In addition to this, the prostheses, in particular the lower ones, are often considered difficult to manage in chewing.

The question now is, whether these factors really do impair the powers of mastication. After all, the food we consume consists mainly of soft substances, which should not be difficult for the wearer of dentures to chew. On the other hand, firm, firm and brittle, and tough substances perhaps are hard for them to chew. The patient was asked to say which substances gave him trouble. The opinions given here agreed, on the whole, with one another, being briefly as follows. Of the soft foodstuffs, such as were of an adhesive nature, e. g. soft bread, pancakes and the like, were considered hard to chew. The trouble here was that the under jaw sticks in the mouthful and may then easily get out of position. Firm, and firm and brittle substances were not considered troublesome, on the other hand. On the contrary, it was generally maintained that hard bread was easy to chew, and far preferable to soft bread. Nor did the test subjects find raw carrot, fresh fruit etc. difficult, provided the mouthful was not very large. Tough meat was considered troublesome. A number of test subjects said that meat could be chewed: others said that they ate meat cut up into small pieces and swallowed without any real chewing previously.

The general impression the author got from these questions was that adhesive and tough food substances cause trouble in chewing, while soft, firm, and firm and brittle substances are comparatively easy to cope with.

Prosthesis and number of chews.

When the specimens were taken, the number of chews was counted in the same way as before. Table 61 gives average values for the number of chews taken by men and women with extremely good, good and bad prostheses in chewing the portion until it felt ready to swallow. The figures in the table show that the number of chews increases from extremely good to bad prostheses, both in men and women. The difference between the number of chews with extremely good and with bad prostheses is just about probable for men (27.0 ± 11.0). A comparison between the mean number of chews for men and for women shows that, on an average, the men chew a greater number of times. The greatest difference between

TABLE 61.

Number of chews in men and women with full prostheses of varying quality. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation. V = variation coefficient.

Prosthesis	Men				Women			
	n	$M \pm \varepsilon(M)$	σ	V	n	$M \pm \varepsilon(M)$	σ	V
Extremely good	17	67.1 ± 5.7	23.7	35.4	8	56.8	—	
Good	19	88.8 ± 4.3	18.5	20.9	22	67.4 ± 5.2	24.3	36.1
Bad	14	94.1 ± 9.5	35.5	37.7	20	78.0 ± 3.7	16.4	21.0
Total	50	82.9 ± 3.9	27.7	33.3	50	69.9 ± 3.0	21.1	30.2

the two sexes is found in chewing with moderately good prostheses. This difference is significant (21.4 ± 6.7). The figures, then, show men with prostheses to have chewed more than women, and also show that men with bad prostheses chew a greater number of times than men with extremely good ones. As the number of investigated women with extremely good prostheses is very small, we cannot see from the figures whether there is a difference there between the number of chews with extremely good and with bad prostheses, though the great difference between the means rather indicates that there is.

A comparison can now be made between the average number of chews for adult men and women with their own teeth, on the one hand (cf. Table 40 and 41), and for men and women with full dentures on the other. In *men,* the values for extremely good dentures agree with those for extremely good sets of teeth. Persons with good full dentures chew, on an average, a larger number of times than adult men with their own teeth. The difference in chews between good sets of teeth on the one side, and good dentures on the other, is statistically significant (21.9 ± 5.7). (The figures for the number of chews with bad dentures is high, but has at the same time a high standard error, and give no significant difference between bad sets of teeth and bad dentures.) A comparison of the number of chews between *women* with their own teeth and women with full dentures shows in the same way as for men, tallying values for extremely good sets of teeth and extremely good dentures. The number of chews in good and bad dentures is higher than in good and bad sets of teeth, with a significant difference between bad sets of teeth and bad dentures of 19.4 ± 4.9. These compa-

risons indicate that persons with good dentures do not, on an average, chew more times than persons with their own teeth, whereas persons with good and bad dentures do.

Prosthesis and mastication coefficient.

This difference in the number of chews may, as far as the masticatory effect is concerned, compensate the lower effectivity of bad dentures, so that there is no noticeable difference in the comparison of mastication coefficients between good and bad dentures. There is therefore reason to compare the mastication effect in good and in poor prostheses when the number of chews is constant, i. e. 40. Figures are given in Table 62.

We find for men that there is a statistically significant difference in mastication coefficient between extremely good and bad dentures (difference 7.2 ± 1.5), and also between extremely good and good dentures (5.5 ± 1.4). On the other hand, the difference between good and bad dentures is not significant; this may be due to elements of uncertainty in classifying. There is, however, a probable difference (2.11 ± 0.82) for women between these groups of dentures.

It now remains to compare the mastication effect between persons with full dentures and persons with their own teeth. If we compare the different groups of dentures, we find no statistically significant or probable differences between the groups in unrestricted chewing; this implies that people with bad prostheses compensate the lowered effectivity by chewing a larger number of times. In itself, this is, perhaps, not so astonishing. We can suppose that a person who has been given false teeth will chew under such altered circumstances as to cause him to break his earlier habits. In developing new ones, he pays a certain attention to the mastication effect. All the same, it is possible that the increased number of chews does not entirely level out the differences, in so far as we find a difference of 6.0 ± 2.5 for the average mastication coefficients between the groups of good and bad dentures in men. It is possible, that is to say, that we should get a significant difference on a larger material. Since, in each group, the number of persons with full dentures is small, we get better criteria if we compare the mastication coefficients for the total number of men and women respectively.

TABLE 62.

Mastication coefficients in tests with 40 chews for men and women, divided into groups with prostheses of varying quality. n = number of persons. $M \pm \varepsilon(M)$ = mean ± standard error. σ = standard deviation. V = variation coefficient.

Prosthesis	Men				Women			
	n	$M \pm \varepsilon(M)$	σ	V	n	$M \pm \varepsilon(M)$	σ	V
Extremely good	17	22.74 ± 1.14	4.68	20.6	8	17.48	—	—
Good	19	17.29 ± 0.88	3.83	22.1	22	17.61 ± 0.66	3.09	17.5
Bad	14	15.58 ± 0.91	3.39	21.8	20	15.50 ± 0.48	2.15	13.9
Total	50	18.66 ± 0.70	4.93	26.4	50	16.74 ± 0.40	2.86	17.1

If, then, we lump together the entire material, we find for men a mastication coefficient of 24.08 ± 0.94, and a standard deviation of 6.65 ± 0.66. The variation coefficient is 27.6 ± 2.76 per cent. For women, the mean is 20.47 ± 0.63, the standard deviation 4.41 ± 0.44, and the variation coefficient 21.7 ± 2.17 per cent. There is a small significant difference between men and women with dentures, possibly partly connected up with the fact that women with dentures chew a lesser number of times than men with dentures (difference 3.61 ± 1.13). It must be remembered, however, that the average age of the women is higher than the average age for the men.

The main interest centres round a comparison with the figures for adult men and women with their own teeth (cf. Table 49). We find that persons with full dentures have a mastication effect which is not significantly different from that in men with extremely good teeth, but which is perhaps somewhat lower. The same is true of women. It is interesting to be able to ascertain that prosthesis gives, on an average, about as good a result as an extremely good or good set of teeth when chewing a substance which, though not representing in consistency the food which is most troublesome to chew, nevertheless borders on the upper limit of difficulty for normal food. The results obtained here agree with the details given by the patients themselves, which have been described earlier on. Full prosthesis gives, as a rule, a satisfactory or even good mastication effect.

It is finally of interest to discuss, in this connection, the variability in mastication effect. We have shown earlier on that

there are quite marked differences between well and badly made prostheses. It is also found in the investigation of the mastication coefficient that, despite the relatively homogeneous nature of the sets of teeth, there is a very large range of variation in the mastication effect. For men, the variation coefficient amounts to more than 25 per cent, for women to more than 20 per cent. The range of variation is, actually, so large that the least effective prostheses give a result which is worse than the average ones obtained in poor sets of teeth.

Taking this into consideration, it is of particular interest to investigate the lower limit for the range of variation. We then find that if we reckon with a downward range of variation of 2 σ, the lower limit for men with extremely bad sets of teeth lies at 9.15, and for men with prostheses, at 10.78. The corresponding values for women are 11.92 and 11.59. In other words, bad replacements in an extremely poor set of teeth do not necessarily improve the situation, whereas good dentures can raise the mastication effectivity to a level considerably over the average one in people with extremely good teeth. We should remember in this connection, however, that the group of persons with their own teeth who were considered to have extremely poor sets were not completely toothless; they always had the incisors and a grinder pair or so left. The individuals with the worst sets of teeth had an occlusion surface of about 40—45 sq. mm. As the problems in this sphere have practical importance, special tabulations have been made with a view to getting further information. We have been able to ascertain that the average differences between extremely good and extremely bad sets of teeth are not particularly great, and are less than what we might have expected. It has furthermore been found that there is a great variation in mastication effectivity in sets of teeth of a fairly similar nature. To illustrate how great a part the variability plays here from a practical point of view, we have investigated how often the masticatory effectivity in groups of varying sets is above the average for adult men and adult women respectively (Table 63). As expected, we get higher figures in good sets than in poor. Persons with extremely good sets of teeth have a masticatory effect which is in 80 per cent better than the population's average, while in extremely bad sets, not quite 15 per cent exceeds this average. Nevertheless, this shows that some persons with extremely bad

TABLE 63.

Number of individuals (= n) in groups with sets of teeth in varying condition, distributed according as the mastication coefficient is greater or smaller than the average mastication coefficient for the total number of examined men and women respectively, and average number of chews (M_n) in the groups in question. N = total number of persons. M = mean

Set of teeth	N	Above M			Below M		
		n	n in % of N	M_n	n	n in % of N	M_n
Men							
Group I: extremely good	63	50	79.4	72.1	13	20.6	55.2
» II: good	60	23	38.3	83.0	37	61.7	56.9
» III: bad	51	10	19.6	89.2	41	80.4	66.2
» IV: extremely bad	55	8	14.5	76.5	47	85.5	63.3
Women							
Group I: extremely good	61	52	85.2	67.2	9	14.8	41.0
» II: good	76	40	52.6	77.2	36	47.4	49.1
» III: bad	50	13	26.0	76.1	37	74.0	63.8
» IV: extremely bad	50	6	12.0	100.5	44	88.0	73.8

sets of teeth can also chew as effectively, or better, than the average in a population of adult men and women.

It is, perhaps, more interesting to try and get an idea of how far the chewing of persons with varying sets of teeth is above the average for persons with extremely bad teeth (cf. Table 64). Here, too, we find considerably higher figures for extremely good sets of teeth than for extremely bad ones. About half of those with extremely bad sets are above the group mean, which is, of course to be expected. A more important fact is, that among persons with extremely good sets of teeth, 7—8 per cent chew worse than the average mastication for persons with bad sets. In other words, the low mastication effect in these former is not due to lack of teeth. If they wish to make the effort, they can of course achieve a very good effect. Their chewing habits are such, however, that they content themselves with a poor effect.

It has been said earlier on that, when we are to investigate the mastication effect in separate individuals with the help of the test tried out here, we get an uncertain value from a single test, but that a series of tests should lead to a fairly exact impression. In most cases, about ten tests should be enough, which implies that we have to reckon with a standard error of about 3

TABLE 64.

Number of individuals ($=n$) in groups with sets of teeth in varying condition, distributed according as the mastication coefficient is greater or smaller respectively than the average mastication coefficient for the group with extremely bad sets of teeth (men and women), and average number of chews (M_n) in the groups in question. N = total number of persons. M = mean.

Set of teeth	N	Above M			Below M		
		n	n in % of N	M_n	n	n in % of N	M_n
Men							
Group I: extremely good	63	58	92.1	70.1	5	7.9	51.2
» II: good	60	45	75.0	72.9	15	25.0	48.7
» III: bad	51	28	54.9	82.5	23	45.1	56.4
» IV: extremely bad	55	23	41.8	77.0	32	58.2	56.8
Women							
Group I: extremely good	60	56	93.3	57.7	4	6.7	32.3
» II: good	76	56	73.7	64.6	20	26 3	42.6
» III: bad	50	24	48.0	66.3	26	52.0	51.4
» IV: extremely bad	50	22	44.0	77.3	28	56.0	50.0

per cent. When this has given us an idea of how effectively the test subject chews with the set of teeth he has, we can fit him into the scale of varying mastication coefficients characterizing a normal population. If the test subject has a low mastication coefficient, there is reason to discuss prosthesis. The nearer he is to the lower limit for normal effectivity, the greater, of course, is the call for prosthesis from the point of view of effective chewing; greatest of all is it if he is below the value denoting the average for extremely bad sets of teeth, namely 15.77 sq. cm./c. cm. for men and 17.16 sq. cm./c. cm. for women. For purposes of comparison, it may be mentioned that 8 ± 3.8 per cent of the men with full dentures, and 18 ± 5.1 per cent of the women, have lower mastication coefficients than the average for men and women respectively with extremely bad teeth.

But we cannot, of course, judge the situation solely with regard to the mastication coefficient. We should also observe the chewing habits of the test subject, i. e. his average number of chews. It is therefore desirable, when testing a patient, to register the number of chews, and get a mean from them. If the figure is low, this naturally indicates that he is content with a comparati-

vely ineffective chewing. Even with an extremely good set of teeth, he would have had a comparatively low mastication effectivity. In consideration of this, we can, naturally, tolerate a lower mastication coefficient in a person like this than in a person with a large average number of chews.

Finally, let it be *firmly* laid down that the indications for prosthesis do not only consist of a poor mastication effect and a low mastication coefficient. Regard must also be paid to the nature of the set of teeth, and to the risk of faulty positions and alterations of different kinds being set up if prosthetic replacement is not made. This side of the matter is outside the scope of this work, however. All the same, an all-round estimation of the need of dentures should get a certain guidance from the results of an investigation with mastication test. From a practical point of view, we may lastly stress, in this connection, the importance of the way in which the dentures are made, and how the subjects can learn to use them. The points of view now put forward concern full dentures. Thus, the conclusions cannot be applied to partial dentures of various kinds. To judge these, special investigations are of course necessary.

For the sake of safety, we may once again remind readers that the conclusions drawn refer only to the test material which the author has used, and to food which has a corresponding consistency. Obviously, entirely different results are to be expected in chewing substances which are easier to reduce, as also in chewing substances with a more resistent consistency. Of course the size of the test portion is also of a certain importance. In other words, this investigation should be followed up with research into such questions.

Summary.

The survey of the literature shows that little attention has been paid to the question of the physiological effect of the teeth in normal and in more or less defective sets. A few investigations have been carried out with straining of chewed test portions. The materials (almond, cocoanut) used in the tests were of a not very satisfactory nature. The methods used were uncertain, and did not succeed in giving any more definite idea of the mastication effect under different circumstances. Larger materials, and more representative ones, have not been investigated at all. It has therefore been necessary in the first place to work out a satisfactory *method for testing.*

1. After testing different materials, the one chosen was 15 per cent gelatin to which had been added 5 per cent barium sulphate and a red colouring-matter. From this cylindrical rods are cast, which are cut in a special apparatus (cf. Figure 1) into pieces with a volume of 10.6 c. cm. (7.4 c. cm. for children). The pieces are hardened in formalin, so that they do not dissolve in water. The formalin is subsequently removed by washing. The test material should answer reasonable demands in so far as it can be chewed even by people with poor teeth, without, however, being unduly easy to reduce to small pieces. Its consistency most nearly corresponds to that of raw carrot or boiled liver. The test material has been submitted to special tests to ascertain its compressibility and to establish the breaking-point in loading, and has proved to have a homogeneous character. A special apparatus has been constructed to carry out such tests (cf. Figure 2).

2. After the test portion has been chewed, the reduction is determined by straining through an apparatus (cf. Figure 3) consisting of a thick tube, with 10 strainers with the diameter of the holes going from 10 to 1 mm., there being 1 mm.'s difference between each. A rotating stream of water plays on the portion. The direction of the rotations is reversed after 48 seconds, with

pauses of 12 seconds. The water pressure is 1 metre. The straining of one test portion takes 6 minutes.

3. When establishing the degree of reduction, the first thing is to count the particles in the first 7 strainers. The number of particles in the last 3 are determined by sedimentation in graduated glass tubes when the particles are shaken down by a mechanical device. A special investigation has determined the number of particles per c. cm. of sedimented volume.

4. To get a uniform expression for the degree of reduction, a calculation is made of the total area of the particles composing the test portion after it has been chewed. In so doing, it is assumed that the particles on the first 7 fractions have, on an average, the form of cubes, whose sides have an average diameter lying between the holes in the strainer where the particle landed up, and the one immediately above. In the last 3 fractions, the particles are assumed to have, on an average, the shape of octahedrons, with diameters as the cubes. By means of a special investigation, it has been established that it is possible on these assumptions, to calculate with sufficient exactitude the volume of the test portion from the number of particles. The calculated volume diverges from the actual one with a standard deviation of about 10 per cent.

The calculated surface area has been checked by staining the portion with Congo-red, which is absorbed by the surface of the particles. After washing with water, the colour is dissolved with a certain quantity of 96 per cent alcohol, and the colour content determined colorimetrically. Colouration and decolouration of this kind, carried out on slices of gelatin with a known area, have given coefficients for the reckoning of the colorimetrical values in sq. cm. of surface. The values thus obtained have agreed fairly well with those for the geometrically calculated surface for a series of 16 portions.

5. The values obtained for volume and surface area have been used to compute a *mastication coefficient* which gives sq. cm. of area per c. cm of volume in the test portion. It is difficult to get a general survey of the size of the different fractions. The coefficient, however, gives a simple expression for the portion's degree of reduction. The coefficient is probably closely connected with what, from a physiological point of view, one wants to measure. The reduction of the test portion is, of course, of

importance, because mastication extends the surface so that the digestive juices have better play in the process of digestion. By double determinations of the mastication coefficient in a series of portions, the error of measurement has been established at 2.1 per cent, which can be considered small in view of the variability found when one person chews the test material in repeated tests. The individual variability in chewing nevertheless makes it necessary, when establishing the masticatory effectivity of a single person, to have him carry out a small number of tests, e. g. about 10, to get a reliable mean value. (The standard error for a mean of 10 tests should be about 3 per cent.)

* * *

Using the methods worked out, *investigations have been made on a series of persons* of different ages and sex, and with more or less defective sets of teeth, and also on persons with full dentures; this was to get material for a closer analysis of the masticatory effectivity. The investigated material consists of 917 persons, distributed as follows: 100 7-year-old boys and girls, 100 13-year-old boys and girls (schoolchildren from Stockholm), 229 grown-up men (called up for military service), 237 grown-up women (female factory hands in Stockholm) — both groups 20—45 years of age — 101 older men and 50 older women of 50—75 years of age (selected material), and 50 men and 50 women of about 40—80 years of age (the majority between 55 and 70) with full dentures.

6. A special statistical treatment has been carried out as to the nature of the teeth, in order to characterize the material from a functional point of view. The statistical analysis has been made more thoroughly for the groups which can be considered as fairly representative for their respective layer of society. The set of teeth has been judged both with regard to its number of teeth, and with regard to teeth in occlusion, when (for grinders) the occlusal surface was gauged with the help of a wax impression, or the teeth were assessed according to a point scale. A special investigation has shown there to be a high correlation between the results of these two methods.

a) 7-year-old children, who have a maximum of 24 teeth, have proved throughout to have good ones. Front teeth are missing in 14.9 per cent, and grinders in 28.6 per cent.

b) 13-year-old children, who have a maximum of 28 teeth, have also good teeth. Front teeth are missing in 2.1 per cent, grinders in 8.8 per cent.

c) Grown-up men show a great variation. In the total material, however, incisors are missing only in 1.8 per cent, and grinders in 31.9 per cent.

d) For grown-up women, the corresponding figures are 1.4 per cent and 34.9 per cent. The agreement between men and women is good.

A particularly interesting fact is that, in grown-up men, wisdom teeth are found in 43.3 per cent, and in grown-up women only in 28.1 per cent. It may be mentioned that in a representative material of old men, the wisdom teeth have to a certain extent either not erupted or else have been destroyed early, but that they nevertheless are kept to a ripe old age in an unexpectedly large number, i. e. about 20 per cent. Because of the difficulties of diagnosing wisdom teeth, these figures, however, are not quite dependable.

To characterize the sets of teeth, a *contact coefficient* has been calculated which shows how many teeth correspond on the average to one contact in the table of points used by the author. The sets have further been grouped into four, according to the number of occlusion contacts. The limits have been set at quartiles and median in adult men and women, and this division has proved practicable throughout. (Among 13-year-olds group I, which comprises extremely good sets of teeth, has been split into two.) For grown-up men, for example, the contact coefficient for extremely good sets of teeth is 0.93 teeth, for good sets 1.20, for bad sets 1.36, and for extremely bad sets 1.78. As regards the details for the character of the sets of teeth, see Chapter 11.

7. Using the tried-out method, tests have been made registering the number of chews taken when the subject was allowed to chew until he considered the portion ready to swallow. Special tests have checked that the number of experimental chews agrees with the number taken when the portion is swallowed. It has been found that there are only small differences in the number of chews between grown-up men and women. The average number of chews is 67.0 ± 1.3 for men, and 58.4 ± 1.1 for women. Between groups with variously good sets of teeth there are no significant differences. This means that a poor set of teeth is not com-

pensated by a greater number of chews. There are also no differences either between older men and women and younger ones or as compared with 13-year-olds (if the different sizes of the test portions are taken into account). On the other hand, 7-year-olds seem to take a somewhat lower number of chews than the other groups. Here, the mean is 49.7 ± 1.1. It has further been possible to show that one person admittedly chews a somewhat varying number of times in repeated tests, but that this variability is not very large, consisting of 16.9 per cent for men and 13.3 per cent for women; this means that different individuals have different chewing habits: and that these habits as regards to the test used are quite firm, and fairly independent of the chewing result attained. Special investigations have also been carried out with different materials. They have shown, however, that material which is very troublesome to chew, such as indiarubber, increases the number of chews, while on the other hand, it gets lower for very easily chewed material, such as hard-boiled white of hen's egg.

8. Mastication coefficients have been used to investigate results when tests were made on persons with varyingly good sets of teeth, i. e. with different occlusal surface. Differences in the masticatory effectivity run parallel with deterioration in the sets of teeth. This may be expressed by saying that in grown-up men and women the surface of the original test portion is enlarged 11 times in extremely good sets of teeth, 8 times in good sets, 7 times in bad sets and 6.8 times in extremely bad sets. Nevertheless, the decrease in the mastication coefficient for grown-up men from, say, 24.48 ± 0.89 sq. cm./c. cm. in extremely good sets of teeth to 15.77 ± 0.45 sq. cm./c. cm. in extremely bad sets, is comparatively small compared with the decrease found as regards the occlusion surface. In grown-up men, the mastication coefficient drops by 35.6 per cent from good to extremely bad sets of teeth, while at the same time the occlusion surface drops by 64.3 per cent. For women, the corresponding figures are 29.5 per cent and 64.8 per cent. This means that though the effect of the teeth in a deteriorated set is *not* compensated by increasing the number of chews, it is, to a certain extent, by an increased skill in the management of the mouthful (when use of the incisors probably plays a part). Similar states of affairs have been seen in grown-up women, as also in old people and children. For the rest, there are slight differences between these groups. In a comparison between children and

adults no differences of importance were found. (A special investigation has been made into the influence of the different size of the test portions for adults and for children. It has been found that the difference is compensated by an increased chewing and therefore, figures for the mastication coefficients can be compared.) Older men chew somewhat more effectively in corresponding groups of teeth, which may be due to the teeth being abraded, thereby setting up better contacts between the teeth.

9. An investigation of the variability in the mastication effect has shown this to be relatively large, amounting to 20—30 per cent in groups with fairly similar sets of teeth. This must to a certain extent be due to the varying number of chews, and it has been possible to show that there is a distinct correlation between the number of chews and the mastication coefficient. For adult men, the correlation coefficient is $+0.13 \pm 0.05$, for women, $+0.35 \pm 0.06$. The importance of the number of chews has further been directly shown by comparative tests, when the subjects were made to chew 20 and 40 times respectively. The doubled number meant an increase in the effect by 20—30 per cent. All the same, the varying effect, too, must be connected with variations in the character of the sets of teeth. The correlation between the occlusion surface and the mastication coefficient is of the same order of magnitude as the above-mentioned correlation with the number of chews. It amounts to $+0.62 \pm 0.01$ for the whole group of grown-up men, and to $+0.49 \pm 0.05$ for the whole group of grown-up women. In other words, different chewing habits and differences in the sets of teeth seem to play about an equal part for the variation in the masticatory effect found in a population. Differences in skill and in the anatomy of teeth and jaws and other factors must also be of importance for the range of variation.

Finally, it has been shown that the individual differences in repeated tests give a comparatively moderate variability. For adult men and women alike, it amounts to 35 per cent of the total variability. This individual variation is connected with the fact that the number of chews made in the test varies in one and the same person. The number of chews in a population of adults varies from about 12 to about 165. The mastication coefficient varies from 7 sq. cm./c. cm. to 40 sq. cm./c. cm. for men, and from 10 sq. cm./c. cm. to 40 sq. cm./c. cm. for women. The distribution is

moderately skew as regards both the number of chews and the masticatory effect. Cf. Figs. 7 and 8.

10. A test of the chewing conditions with full dentures has shown that the average number of chews in persons with poor dentures is somewhat higher than that for persons with their own teeth. But there is no difference for good dentures. The effect, measured in mastication coefficient, corresponds on an average to that in extremely good or good teeth. Nevertheless, the variability is great. The prostheses have been classified as extremely good, good and bad; in so doing, regard was paid both to the way they are made and also to other circumstances giving reason to expect some to function better than others. Distinct differences in mastication effect have been found between these groups. At its best, a prosthesis gives a mastication effect as good as in persons with extremely good teeth of their own; at its worst, the effect is below the average obtained in persons with extremely bad teeth. Both when judging the need of dentures and when contemplating the advantages a certain prosthesis offers, the suggested test should prove of use, though in that case it is necessary to repeat it a number of times, e. g. about 10.

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